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# Life cycle environmental and economic analysis of polyurethane insulation in low energy buildings

Prepared for: PU Europe (formerly BING), Av. E. van Nieuwenhuyse 6, B-1160 Brussels

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Protecting People, Property and the Planet

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## Executive Summary

### Purpose

The purpose of this project is to quantify the overall environmental and economic costs of using polyurethane (PU) insulation in low energy buildings. This has been demonstrated by balancing the embodied environmental impact in manufacturing the PU product and similar products with the environmental benefits of reduced energy used for heating and, for the economic analysis, a comparison of the life cycle costs of each.

Three scenarios were modelled using a 3-bedroom, 5-person two-storey detached house, with masonry cavity walls, solid concrete floor and pitched or flat roof. Each scenario considered three different climatic zones: Temperate Oceanic, Temperate Mediterranean and Cool Continental, as referenced in the Köppen Climate Classification.

**Part 1 New building scenario** Using polyurethane, stone wool, glass wool or expanded polystyrene insulation material, as appropriate, in a new build cavity wall, pitched roof and ground floor to achieve target U values and hence the same energy consumption for all scenarios.

**Part 2 Refurbishment scenario** Using 50mm thickness of polyurethane, stone wool or glass wool insulation materials to upgrade (refurbish) the external wall of an existing building with an internal lining, resulting in different U values and hence different energy consumptions

**Part 3 Flat roof scenario** Using polyurethane, stone wool and expanded polystyrene insulation material of varying thicknesses for a flat roof to achieve a common U value and assess the impact of the density of each material.

The report has been formatted as follows:

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<tr><th colspan="3">Executive summary</th></tr>
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**Environmental impacts**

LCA assessments were carried out to investigate the environmental impacts associated with the materials and energy consumption for the alternative designs included in the project. The objective of this work was to consider how the impact of the materials compared with each other and with the impact of energy consumption during use.

The LCA work used a study period of 50 years in line with the life cycle costing part of the project, as requested by the client. Results are presented as characterised and normalised data for the environmental impact categories of Global Warming, Stratospheric Ozone Depletion, Eutrophication, Photochemical Ozone Creation, and Acidification. These indicators were used as they were the impact indicators proposed in TC350 at the time the project was initiated. Data was normalised to the annual impacts of a Western European citizen, covering the EU15 (plus Norway and Switzerland).

*Note: The approach used in this study differs from that of BRE Global's Environmental Profiles Methodology, which underpins the Green Guide to Specification, and therefore the results produced are not comparable with other results published by BRE Global for the environmental impact of construction products or specifications. Section (Introduction to LCA) provides more details of the differences from the Environmental Profiles Methodology.*

The table below summarises the aspects modelled within the LCA work. Part 1 considers the environmental impacts associated with new build, Part 2 investigates refurbishment by applying an internal lining to existing external walls, and Part 3 models flat roofs.

| Part | Element | Climate Zone | Energy for space heating | Insulations | Materials |
|---|---|---|---|---|---|
| 1 | Cavity Wall | • Temperate Oceanic<br>• Temperate Mediterranean<br>• Cool Continental | Gas | • PU<br>• stone wool<br>• glass wool | Brick, dense blockwork, plaster, paint<br>Extra wall, roof & foundations compared with PU wall |
| | Pitched roof | • Temperate Oceanic<br>• Temperate Mediterranean<br>• Cool Continental | n/a | • PU<br>• stone wool<br>• glass wool | Concrete tiles, battens, underfelt, trussed rafters. For ceiling below joists: plasterboard, paint |
| | Ground floor | • Temperate Oceanic<br>• Temperate Mediterranean<br>• Cool Continental | n/a | • PU<br>• EPS | Reinforced concrete, reinforced screed |
| | Whole house | • Temperate Oceanic<br>• Temperate Mediterranean<br>• Cool Continental | Gas | • PU, walls + roof<br>• stone wool, walls + roof<br>• glass wool, walls + roof | External wall, & roof as for each insulation type; all with PU ground floor, upper floor with I-joists, painted timber windows |
| 2 | Internal Lining of external wall (refurbishment) | • Temperate Oceanic<br>• Temperate Mediterranean<br>• Cool Continental | Gas | • PU<br>• EPS<br>• stone wool<br>• glass wool | Plasterboard, plaster adhesive, paint<br>Battens, plasterboard, paint |
| 3 | Flat roof | • Temperate Oceanic<br>• Temperate Mediterranean<br>• Cool Continental | n/a | • PU<br>• stone wool<br>• EPS | EPDM, vapour control layer, OSB, timber joists, plasterboard, paint |

**Summary of models used for the study**

The original project brief requested wood wool (cellulose) board insulation to be assessed in Part 1, new build, pitched roof. However, no suitable LCI data is available in the public domain to allow this product to be included in the LCA work.

The results from Part 1 indicated that the PU designs tended to have similar or higher environmental impacts than those for designs with the alternative insulation materials at the same thermal performance. Part 3's results indicated that when insulations need mechanical properties in addition to their thermal performance, then solutions using PU can have environmental impacts similar to or lower than alternative insulations.

The results from Part 2 show that where the amount of insulation is fixed, rather than the U-value, then the greater energy savings achieved with using PU insulation offset the higher environmental impact of the PU insulation itself.

Part 1 further indicates that the materials of the modelled highly insulated house accounted for around one third of the total Global Warming and 50 to 90% of the whole house impact in Ozone Depletion, Eutrophication, Photochemical Ozone Creation and Acidification for Air and Water over 50 years for all climate zones.

However, the results from Part 2 imply that:

a) if the cavity is kept at the greater thickness needed for stone wool and glass wool in Part 1 to achieve the set U-value of 0.15 W $m^{-2}K^{-1}$ then the extra PU insulation that could be incorporated would save energy in use, which could be enough to offset the extra impact of the PU material, and may offer greater benefits as demonstrated in Part 2;

b) if stone wool and glass wool were modelled at the same cavity thickness as for the PU model in Part 1of this project, it is likely that stone wool and glass wool would require more energy during use, which might more than offset the lower environmental impacts of these insulations.

We would recommend that consideration is given to carrying out the assessments outlined in a) and b) above ensuring that the specifications and energy models are relevant to the climate zones where the models are set.

Additionally, the energy models have assumed a common airtightness and junction y value for all models. The relevance of this assumption to the results is another further area of research.

**Cost impacts**

Life cycle costing (LCC) is a technique to establish the total cost of ownership. It is a structured approach which addresses all the elements of this cost and can be used to produce a spend profile of the asset over its anticipated life-span

LCC estimates were undertaken using BRE's cost model which is compliant with BS/ISO 15686-5 Buildings and constructed assets Service life planning Part 5 life cycle costing. The life cycle costs have allowed for normal maintenance and time expired components as appropriate.

The specification for the elements and the cost of all components are intended to represent the typical cost incurred by building owners. The values in the assessment are based on those required for a two storey detached property with a gross internal floor area of 104$m^2$.

The results for Part 1 cavity wall infill indicates that for all regions considered, 180mm polyurethane insulation used in the cavity has the lowest life cycle cost, followed by 270mm glass wool and 270mm stone wool.

To achieve the required u values, different thicknesses of insulation required different quantities of materials for the wall and hence higher construction costs. An additional cost/$m^2$ for this is included with the new wall calculations.

One effect of a thicker new cavity wall is the additional footprint area required for roof and floor. On a large building site this may affect the density or number of properties that could be built on the site, e.g. in the worst case, 8.00$m^2$ extra on the roof area for each property may mean that only 9 properties could be fitted in an area that may be able to accommodate 10 if the external walls were thinner.

The results for a new pitched roof with insulation between and over the rafters to achieve a common U value indicate that 190mm polyurethane has the lowest life cycle cost when used in all regions followed by 300mm glass wool insulation and 310mm stone wool.

The results for the new ground floor indicates that 95mm polyurethane insulation has the lower life cycle cost when used in all regions, followed by 185mm expanded polystyrene.

The results for Part 2 refurbishment of an existing wall by the addition of 50mm insulation to the inside face indicates that polyurethane insulation has the lowest life cycle cost, followed by expanded polystyrene, glass wool and stone wool in all regions.

The results for Part 3 new warm deck flat roof indicates that 150mm polyurethane has the lowest life cycle cost when used in all regions, followed by 255mm expanded polystyrene and 255mm stone wool insulation.

## Contents

# 1 Description of the project

**Outline of the brief**

BING -The Federation of European Rigid Polyurethane Foam Associations, (now renamed as PU Europe) has asked BRE Global to undertake a research project to examine the life cycle environmental and economic analysis of polyurethane insulation in low energy buildings. This entails carrying out a review of the life cycle costs (LCC) and life cycle assessment (LCA) of polyurethane (PU) insulation in buildings compared with glass wool (GW), stone wool (SW), expanded polystyrene (EPS) or wood wool (cellulose) insulation as appropriate to the location within the building. To do so BRE Global has assumed a 3-bedroom, 5-person two-storey detached house, with masonry cavity walls, solid floor and pitched roof for whole house analysis and flat roof for the flat roof analysis.

Wood wool (cellulose) board insulation has been omitted from this report as no suitable LCI data is available in the public domain to allow this product to be included in the LCA work.

The project brief requires a comparison to be made of the overall environmental impact and cost implications when applying the model to 3 different climate zones, Temperate Oceanic (TO), Temperate Mediterranean (TM) and Cool Continental (CC) as referenced in the Köppen Climate Classification. These climate zones relate broadly to Western Europe (TO), Southern Europe (TM) and Northern Europe (CC). The construction is assumed to be the same, but the energy inputs will vary with the different climatic regions.

The report has been formatted as follows:

| **Executive summary** | | |
|---|---|---|
| **Part 1 New build scenario** | **Part 2 Refurbishment scenario** | **Part 3 Flat roof scenario** |
| Identification of environmental impacts (life cycle assessments) | Identification of environmental impacts (life cycle assessments) | Identification of environmental impacts (life cycle assessments) |
| Identification of cost impacts (life cycle costs) | Identification of cost impacts (life cycle costs) | Identification of cost impacts (life cycle costs) |
| Affect on building footprint of using different insulation materials | | Impact of weight of insulation on building construction costs |
| **Background report – methodology, detailed results for internal reference** | | |

# 2 Identification of environmental impacts

## 2.1 Introduction to LCA

LCA modelling has been undertaken to determine the environmental impacts associated with using different insulation materials during new build (Part 1), refurbishment of existing external walls (Part 2) and for a warm deck flat roof (Part 3).

The following models have been generated:

1. Part 1 – new build with target u values
    a. Cavity walls - plus any additional roof, external brick leaf and foundations (PU, stone wool batts or glass wool batts)
    b. Pitched roof (PU, stone wool or glass wool)
    c. Ground floor (PU or EPS)
    d. Whole house (External walls + roof + ground floor & foundations + upper floor + windows + energy) in use over 50 years
2. Part 2 – refurbishment with target thickness
    a. Internal lining of existing external walls (PU, stone wool, glass wool or EPS – refurbishment materials + energy) in use over 50 years
3. Part 3 – flat roof with target u values
    a. Flat roofs (PU, stone wool or EPS)

These models allow the following comparisons to be made:

1. Part 1, new build
    a. Constructions with each other (insulation & other materials needed)
    b. Whole house models with each other & energy use – within & between climate zones
2. Part 2, refurbishment
    a. Constructions with each other (insulated drylining only)
    b. Constructions & energy use – within & between climate zones
3. Part 3, new flat roof
    a. Constructions with each other (insulation & other materials needed)

The LCA studies have been performed using a methodology based on BRE Global's Updated Environmental Profiles Methodology[1]. The table below addresses the key aspects of methodology, and highlights where modifications to the Environmental Profiles methodology have been made.

| Aspect | BING Study | Modifications to BRE Methodology |
|---|---|---|
| *Study Period* | Any maintenance and replacement over a 50-year study period, plus demolition at or after the end of the study period. | 60-year study period used in Environmental Profiles and Green Guide.<br><br>Data on service life and calculation of replacement factor unchanged. |
| *Indicators* | Global Warming (100-year): kg $CO_2$ equivalents<br><br>Ozone Depletion: kg CFC-11 equivalents<br><br>Eutrophication: kg phosphate ($PO_4$) equivalents<br><br>Photochemical Ozone Creation: kg ethene ($C_2H_4$) equivalents<br><br>Acidification for Air and Water: kg sulphur dioxide ($SO_2$) equivalents | Additional 8 indicators used in Environmental Profiles and the Green Guide. |
| *Indicators: Characterisation Factors* | Characterisation factors are an update of the CML 2002 indicators, based on those in spreadsheet version 2.7 (issued April 2004) which were downloaded from http://cml.leiden.edu/software/data-cmlia.html, as integrated by Pre into the Simapro Software (v 2.02 in 2005). | |
| *Treatment of Group parameters* | Group parameter emissions of VOCs are considered in terms of Photochemical Ozone Creation Potential only, based on characterisation factors (calculated by averaging factors for a given group of emissions) provided in the draft of prEN15804 from 26.8.2009 and earlier. | In the BRE Global Methodology, group parameter emissions are characterised using the methodology proposed in the CML Operational Appendix (Part 2b)[2] to break down group parameters (e.g. emissions of NMVOCs etc) into their individual constituents. Thus a reported emission of a group (eg alkanes) would be considered to be made up of the mass |

[1] The BRE Environmental Profiles Methodology can be downloaded from www,bre.co.uk/greenguide.
[2] Guinée et al, Life cycle assessment: an operational guide to the ISO standards. CML, Leiden University 2000. This can be downloaded in 4 parts from
Part 1: LCA in perspective: http://www.leidenuniv.nl/cml/ssp/projects/lca2/part1.pdf
Part 2a: Guide: http://www.leidenuniv.nl/cml/ssp/projects/lca2/part2a.pdf
Part 2b: Operational Appendix: http://www.leidenuniv.nl/cml/ssp/projects/lca2/part2b.pdf
Part 3: Scientific Background: *http://www.leidenuniv.nl/cml/ssp/projects/lca2/part3.pdf*

| Aspect | BING Study | Modifications to BRE Methodology |
|---|---|---|
| | | proportion of the relevant chemicals from the group listed in Derwent et al (1996)[3] provided in Part 2b. This is done for factors for POCP, Global Warming and Stratospheric Ozone Depletion. |
| *Cradle to Gate LCA Data* | Data for typical European PU manufacture provided by BING, and modelled using ecoinvent v2.0 datasets.<br><br>Data for stone wool and glass wool insulation based on data provided through the Environmental Profiles project from members of Eurisol in the UK, and modelled using ecoinvent v2.0 datasets.<br><br>Data for EPS taken from ecoinvent v2.0.<br><br>Data for natural gas production and combustion used in building energy modelling taken from ecoinvent v2.0.<br><br>All other construction products for the buildings modelled using ecoinvent v1.3.* | Data for PU based on UK Manufacturers only and modelled using ecoinvent v1.3 datasets.<br><br>Data for stone wool and glass wool insulation based data provided through the Environmental Profiles project from members of Eurisol in the UK and modelled using ecoinvent v1.3 datasets.<br><br>Data for EPS taken from ecoinvent v.1.3.<br><br>No building level energy use taken into consideration within Environmental Profiles and the Green Guide – this is covered within BREEAM and the Code for Sustainable Homes.<br><br>All other construction products for the buildings modelled using ecoinvent v1.3. |
| *LCA data for Transport of material to site* | Data from the Environmental Profiles project used. | Data from the Environmental Profiles project used. |
| *Wastage on site* | Data from the Environmental Profiles project used. | Data from the Environmental Profiles project used. |
| *Disposal Routes for construction waste and demolition waste* | Data from the Environmental Profiles project used.<br><br>For PU note this covers 90% landfill and 10% incineration of polyurethane which is representative of UK practice. | Data from the Environmental profiles project used. |

* Note that within this project there was neither time nor budget to update all the underlying LCA models supporting the BRE Global Environmental Profiles Database from ecoinvent v1.3. However as the data for other building materials is largely common and the difference between ecoinvent v1.3 and v2.0 is small, this is not considered to be important.

[3] Derwent RG, ME Jenkin and SM Saunders , 1996. Photochemical ozone creation potentials for a large number of reactive hydrocarbons under European conditions. Atmospheric Environment 30 (2): 181-199.

- Results are presented using characterised and normalised[4] data generated by this methodology and for the five environmental impact categories.

Key assumptions and decisions made during the LCA work are:

- Polyurethane (PU) insulation is pentane-blown
- Other materials for the houses are modelled based on data held in the BRE Global Environmental Profile Database. These are generally for 'as consumed' products in the UK
- Characterised data is normalised using the annual impacts of a European citizen (EU15 plus Norway & Switzerland) – this data has been taken directly from those provided by CML in spreadsheet version 2.7 (issued April 2004) which were downloaded from http://cml.leiden.edu/software/data-cmlia.html, as integrated by Pre into the Simapro Software (v 2.02 in 2005).
- The modelled constructions are assumed to be the same for all zones studied. Calculation of service life is based on the BRE Global's Environmental Profiles Methodology[5] and has been used for all climate zones.
- Energy sources for all space heating is natural gas.
- U-values for modelled new build elements are lower (better) than required for English building regulations meaning that the modelled designs use less energy than would be the case for current UK practice. This results in materials having an increased relative importance in overall building impact.

The following sections present the results for each of the three parts of the assessment and discuss the implications of these results; the final section draws conclusions from the work and presents some recommendations for further study.

## 2.2 Part 1 New build LCA

This section presents the normalised and characterised data for the assessment of the following new build specifications:

a. Cavity walls with a common U value – PU; stone wool; glass wool, plus extra brick outer leaf, roof & footings for the stone & glass wool options as they will require a thicker wall construction.

b. Pitched roof with a common U value – PU; stone wool; glass wool

c. Ground floor with a common U value – PU; EPS

d. Whole house with common U values – PU (external walls + roof + ground floor + upper floor + windows + energy in use); stone wool (external walls + roof + ground floor with PU + upper floor + windows + energy in use); glass wool (external walls + roof + ground floor with PU + upper floor + windows + energy in use).

[4] To the annual impacts of a European citizen (EU15 plus Norway & Switzerland).
[5] More detail is given in BRE Information Paper IP 1/09, Performance and Service Life in the Environmental Profiles Methodology and Green Guide to Specification, IHS BRE Press, 2009.

Assessments a-c were undertaken over a 50-year study period, covering the environmental impacts of the building materials used to build the house, and any maintenance, replacement over the study period and demolition at or after the end of the 50-year study period. For d – the whole house assessment, in addition to the materials assessment above, it also includes the environmental impacts associated with space heating over the 50-year study period, for three climatic zones, Cool Continental, Temperate Oceanic and Temperate Mediterranean.

## Cavity wall

The characterised data for the new build cavity walls is presented in Table 1.

| Cavity Walls | Characterised | | | | |
|---|---|---|---|---|---|
| | Global Warming | Ozone Depletion | Eutrophication | Photochemical Ozone Creation | Acidification for Air and Water |
| | kg | kg | kg | kg | kg |
| Wall materials (stone & glass wool insulation) | 8,730 | 0.0117 | 5.71 | 7.05 | 55.4 |
| Wall materials (PU insulation) | 8,590 | 0.0116 | 5.65 | 6.95 | 54.4 |
| Extra roof (stone & glass wool insulation) = 3m$^2$ | 82 | 0.000189 | 0.109 | 0.219 | 1.98 |
| Extra foundation (stone & glass wool insulation) = 3m | 574 | 0.000325 | 0.351 | 0.254 | 2.56 |
| Stone wool insulation | 2,130 | 0.000400 | 1.06 | 1.05 | 14.1 |
| Glass wool insulation | 1,450 | 0.000264 | 0.95 | 1.05 | 5.85 |
| PU (pentane blown) insulation | 3,830 | 0.000235 | 3.3 | 6.38 | 22.4 |
| **Totals** | | | | | |
| Stone wool total (materials + insulation) | 11,516 | 0.0126 | 7.23 | 8.57 | 74.1 |
| Glass wool total (materials + insulation) | 10,836 | 0.0125 | 7.12 | 8.58 | 65.8 |
| PU (pentane) total (materials + insulation) | 12,420 | 0.0118 | 8.9 | 13.3 | 76.9 |

**Table 1** Characterised data for the new build cavity walls.

The data from Table 1 is summarised graphically in Figure 1 below.

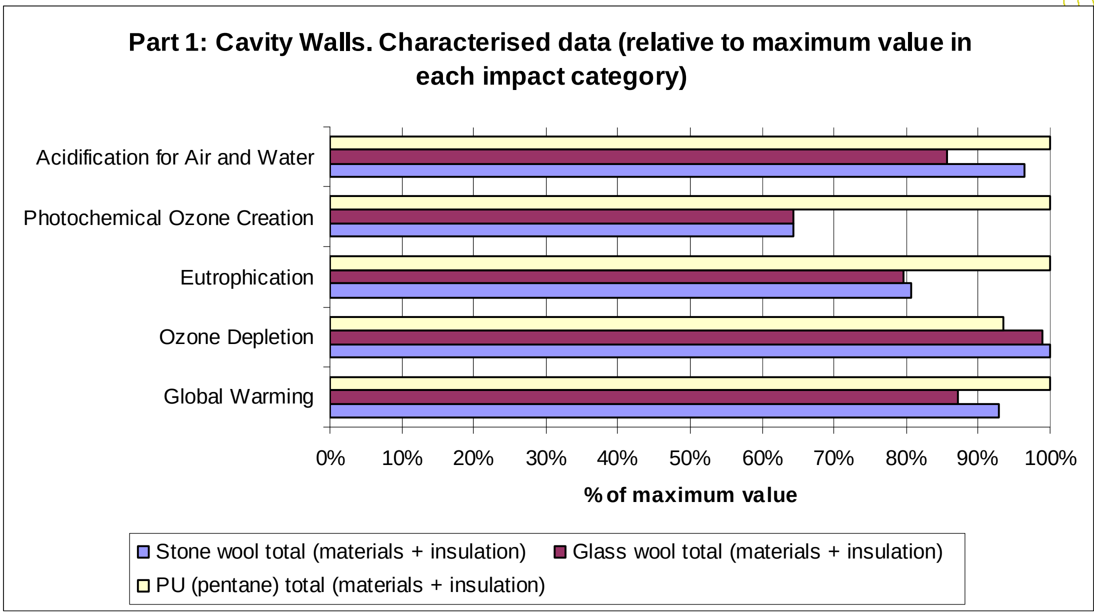



**Figure 1** Part 1 Cavity wall with glass wool, stone wool or PU insulation (characterised).

The results in Figure 1 are the characterised data expressed as a proportion of the maximum impact in each category. The results show that the PU design had the highest impacts in four of the categories; the exception being Ozone Depletion, where the stone wool design had the greatest impact and the PU design the least.

The data in Table 1 indicate that the stone wool and glass wool options were 64 to 96% of the level of impacts found for the PU design in Global Warming, Eutrophication, Photochemical Ozone Creation and Acidification for Air and Water; the greatest difference being in the Photochemical Ozone Creation category.  The least difference between the impacts was in the categories of Global Warming and Acidification for Air and Water. For Ozone Depletion, the glass wool design was 1% lower than the stone wool design and the PU was 7% less than the glass wool design's impact.

The insulations accounted for only 2 to 3% of their design's Ozone Depletion impact. The stone wool and the glass wool insulations accounted for 9 to 19% of their design's impacts in the other four categories. The PU insulation accounted for 29 to 48% of its design's total impact in these other categories, with the proportion being highest in Photochemical Ozone Depletion.

Normalising the data allows the levels of impact in each category to be seen in the context of the background levels of these impact categories. Since normalised data is in the same units[6] the levels of impact in each category can be compared directly with each other.

[6] The units are 'impact per person per year', so a normalised impact of one equates to the same impact as that caused annually by a single Western European citizen.

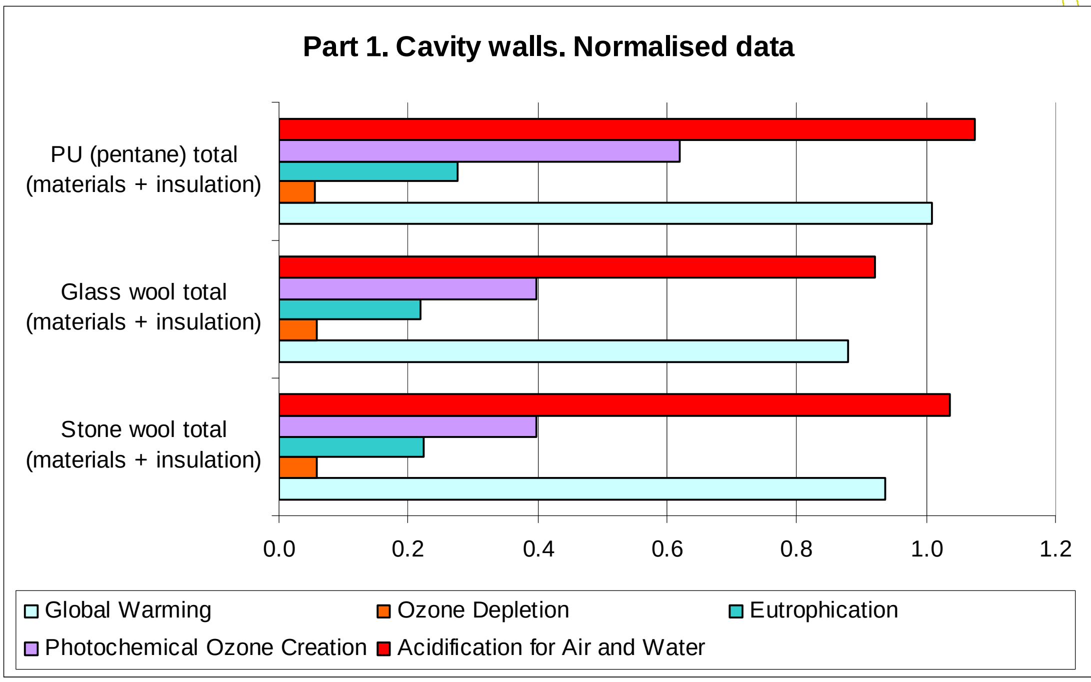



**Figure 2** Part 1: Cavity wall with glass wool, stone wool or PU insulation (normalised).

The normalised impacts presented in Figure 2 show that, for all designs studied, Acidification for Air and Water was the highest impact, followed by Global Warming, Photochemical Ozone Creation, Eutrophication and Ozone Depletion.

### Pitched roof (insulation on slope)

Appendix 2 describes how the different solutions to achieve the target U-value have been achieved. The characterised results are presented in Table 2.

| Pitched Roofs | Characterised | | | | |
|---|---|---|---|---|---|
| | Global Warming | Ozone Depletion | Eutrophication | Photochemical Ozone Creation | Acidification for Air and Water |
| | kg | kg | kg | kg | kg |
| PU (pentane) | 2,360 | 0.000150 | 1.99 | 3.83 | 13.8 |
| roofing materials (PU) | 1,920 | 0.00332 | 1.90 | 4.26 | 44.2 |
| Stone wool | 2,680 | 0.000502 | 1.33 | 1.31 | 17.8 |
| roofing materials (stone wool) | 1,560 | 0.00410 | 2.11 | 4.68 | 45.6 |
| Glass wool | 769 | 0.000140 | 0.502 | 0.56 | 3.1 |
| roofing materials (glass wool) | 1,280 | 0.00458 | 2.22 | 4.91 | 46.3 |
| **Totals** | | | | | |
| Stone wool total (materials + insulation) | 4,230 | 0.00460 | 3.43 | 5.99 | 63.3 |
| Glass wool total (materials + insulation) | 2,050 | 0.00472 | 2.72 | 5.47 | 49.4 |
| PU (pentane) total (materials + insulation) | 4,280 | 0.00347 | 3.89 | 8.09 | 58.0 |

**Table 2** Characterised data for the new build pitched roofs.

The results for the total impact of each design presented in Table 2 are shown in Figure 3 below.

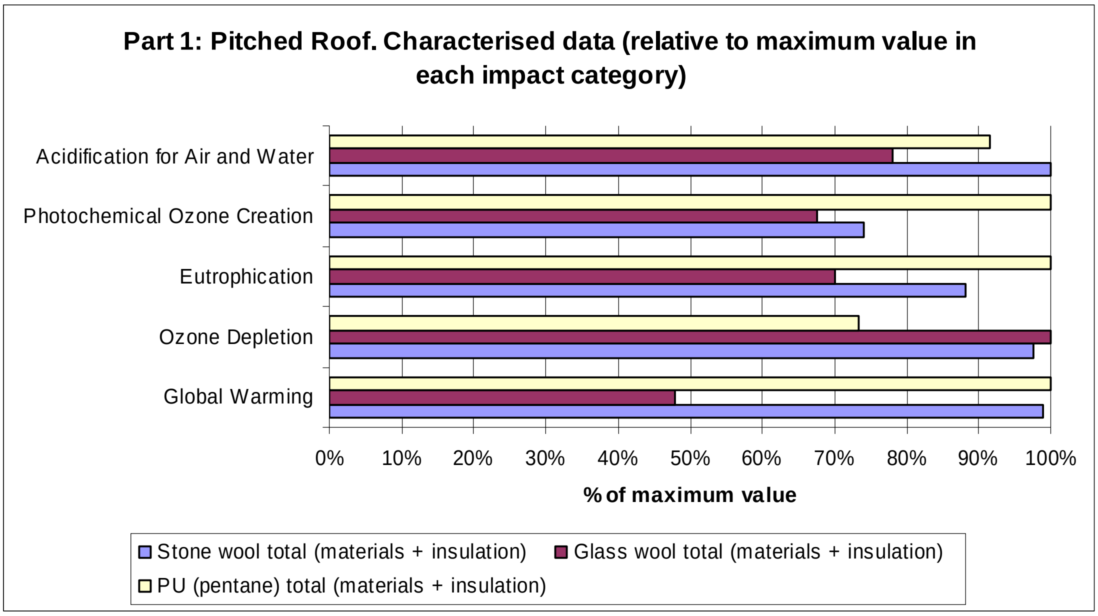



**Figure 3** Part 1: pitched roof with PU, stone wool and glass wool insulation (characterised).

The characterised data in Figure 3 shows that the PU solution had the highest impacts in Global Warming, Eutrophication and Photochemical Ozone Creation, second highest in Acidification for Air and Water, and the lowest in Ozone Depletion. For Acidification for Air and Water, the stone wool design had the highest impact, whereas for Ozone Depletion the glass wool had the greatest impact.

From Table 2, for Eutrophication and Photochemical Ozone Creation, the impacts of the stone wool and glass wool designs were between 68 and 88% those of the PU solution. For Global Warming, the glass wool design's impact was less than half that for both the stone wool and the PU designs, with the impact of the stone wool design only 1% less than the PU solution's impact. The Ozone Depletion of the stone wool design was 3% lower than the glass wool design's impact, and the PU option was 27% less.

The PU insulation accounted for 4% (Ozone Depletion) to 55% (Global Warming) of the impact of the PU design. The stone wool insulation accounted for 11%(Ozone Depletion) to 63% (Global Warming) of its design's impacts and the glass wool insulation represented 3% (Ozone Depletion) to 38% (Global Warming) of its solutions' impacts.

The normalised results are presented in Figure 4 below to compare the impacts of the roofing materials and the insulations.

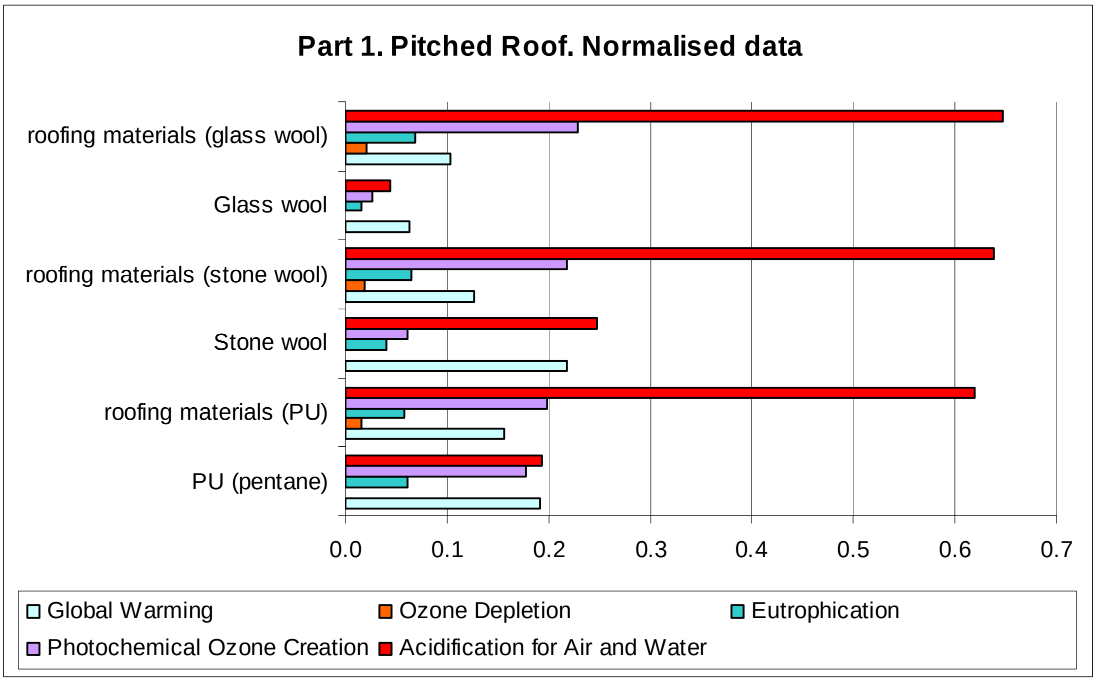



**Figure 4** Part 1: pitched roof with PU, stone wool and glass wool insulation (normalised)

The normalised results in Figure 4 show that Acidification for Air and Water was the largest relative impact for the roofing materials for all the designs, and that the impacts in Ozone Depletion were the smallest. The results also show that the Ozone Depletion of the insulations was vanishingly small.

For the glass wool solution, the impacts of the insulation were largest for Global Warming and Acidification for Air and Water but these were much smaller than the impacts of the roof materials. The stone wool also had the largest impacts in Acidification for Air and Water and Global Warming, and, whilst the stone wool was generally of lower impact than the roof materials, the Global Warming of the stone wool was greater than for the roof materials.

For the PU, the insulations' highest impact was in Acidification for Air and Water, closely followed by Global Warming and Photochemical Ozone Creation. The PU insulation had higher impacts than the roof materials for Global Warming, and very similar impacts to the roofing materials for Photochemical Ozone Creation, and Eutrophication.

## Ground floor

Appendix 2 describes how the different solutions to achieve the target U-value have been achieved. The characterised data is presented in Table 3.

| Ground Floors | Characterised | | | | |
|---|---|---|---|---|---|
| | Global Warming | Ozone Depletion | Eutrophication | Photochemical Ozone Creation | Acidification for Air and Water |
| | kg | kg | kg | kg | kg |
| Ground floor materials | 5,280 | 0.00230 | 2.98 | 2.14 | 23.1 |
| PU (pentane) | 763 | 0.0000484 | 0.65 | 1.24 | 4.48 |
| EPS | 839 | 0.0000646 | 0.266 | 1.80 | 2.98 |
| **Totals** | | | | | |
| PU (pentane) total (materials + insulation) | 6,040 | 0.00235 | 3.62 | 3.38 | 27.5 |
| EPS (pentane) total (materials + insulation) | 6,120 | 0.00236 | 3.24 | 3.94 | 26.0 |

**Table 3** Characterised data for the new build ground floors insulated with PU and EPS.

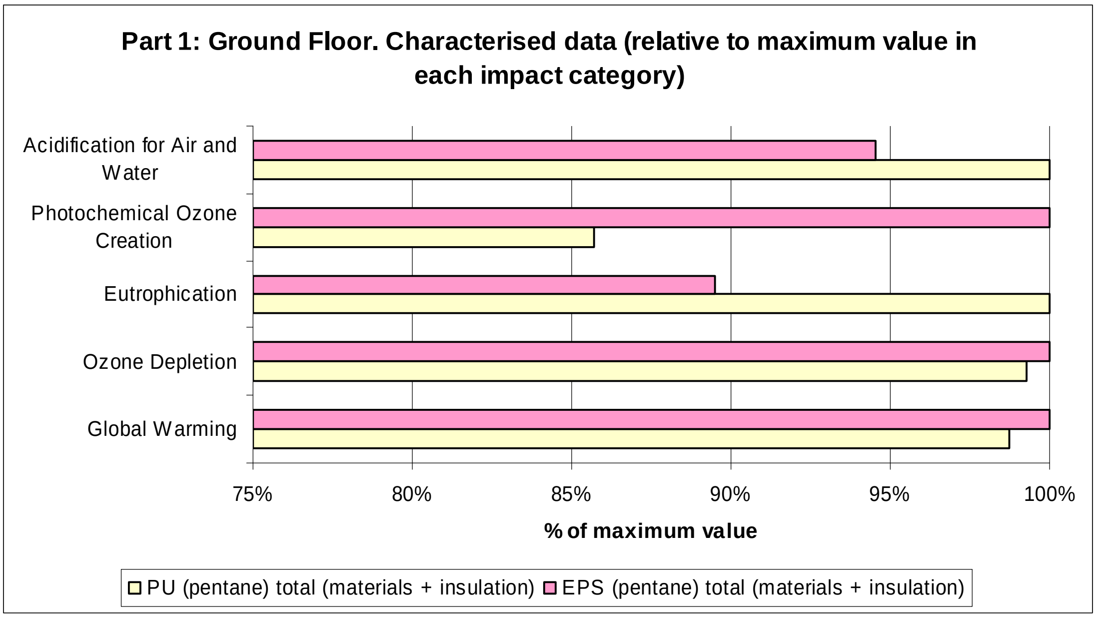



**Figure 5** Part 1. Ground floor with PU or EPS insulation (characterised).

The characterised data in Figure 5 shows that the impacts of the PU solution were greater for Eutrophication and Acidification for Air and Water but the EPS design's impacts were greater for Global Warming, Ozone Depletion and Photochemical Ozone Creation. From Table 3, the PU insulation was responsible for 2% (Ozone Depletion) to 37% (Photochemical Ozone Creation) of its solution's impacts. The EPS was the source of 3% (Ozone Depletion) to 46% (Photochemical Ozone Creation) of its design's impacts.

The normalised results are set out in Figure 6 below.

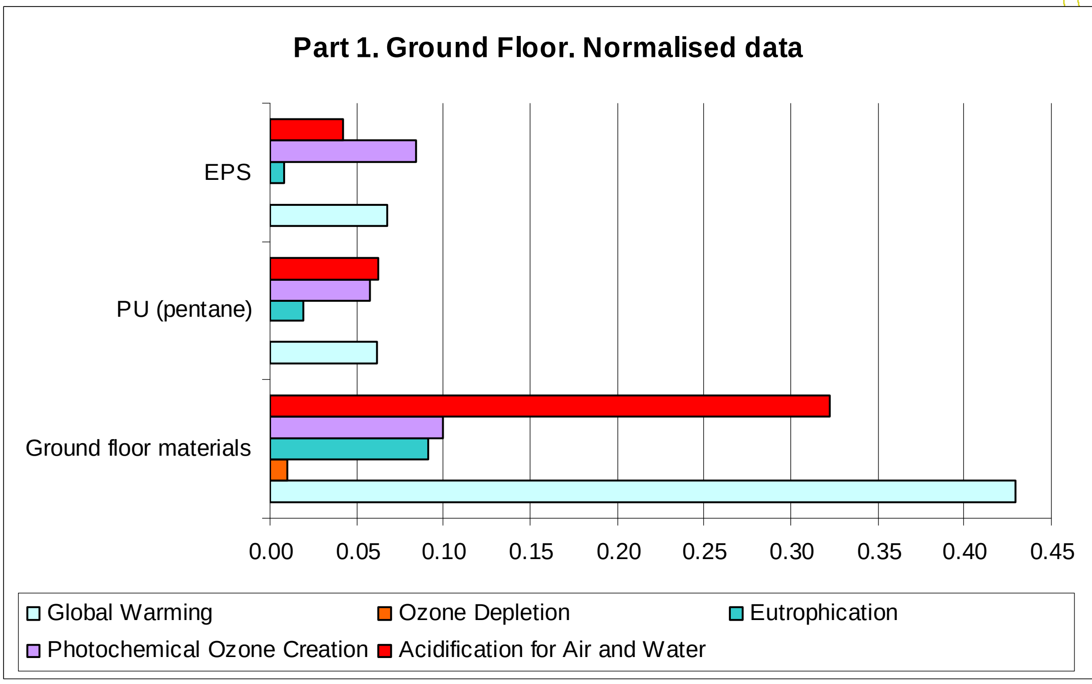



**Figure 6** Part 1: ground floor with PU or EPS insulation (normalised).

Figure 6 indicates that the ground floor materials, which are common to both solutions, had higher impacts in all categories than the insulations. Both insulations' impacts were highest in Photochemical Ozone Creation, Acidification for Air and Water and Global Warming. Ozone Depletion is again shown to be a relatively small impact for both insulations and the designs containing each of them.

**Whole house models**

The three whole house models have been put together using the results from the assessments of the external walls, the pitched roofs and the PU ground floor in combination with an upper floor of timber I-joists with the same area as the ground floor and double glazed softwood windows according to the amount in the 3-bedroom house model.

The models have assumed that the same insulation is used in the external walls and the pitched roof. The PU ground floor was used for all as it was, marginally, the worst-case scenario assessed.

The energy source has been assumed to be natural gas for all climate zones: energy use is that for space heating and not the provision of energy necessary for lighting, cooking, refrigeration, entertainment etc.

Appendix 2 describes how the different solutions to achieve the target U-value have been achieved.

**Model 1: PU insulation**

The characterised data is presented in Table 4.

| Model 1 | Characterised | | | | |
|---|---|---|---|---|---|
| | Global Warming | Ozone Depletion | Eutrophication | Photochemical Ozone Creation | Acidification for Air and Water |
| | kg | kg | kg | kg | kg |
| Wall materials (PU insulation) | 8,590 | 0.0116 | 5.65 | 6.95 | 54.4 |
| PU (pentane blown) insulation | 3,830 | 0.000235 | 3.30 | 6.38 | 22.4 |
| roof materials | 1,920 | 0.00332 | 1.90 | 4.26 | 44.2 |
| PU (pentane) | 2,360 | 0.000150 | 1.99 | 3.83 | 13.8 |
| Ground floor materials | 5,280 | 0.00230 | 2.98 | 2.14 | 23.1 |
| PU (pentane) | 763 | 0.0000484 | 0.65 | 1.24 | 4.48 |
| Upper floor (timber I-joist with chipboard plus plasterboard ceiling below) | 293 | 0.00133 | 1.25 | 1.63 | 22.5 |
| Window (preservative treated, painted softwood, high quality, double glazed) | 3,460 | 0.00670 | 3.57 | 20.60 | 30.2 |
| **Totals** | | | | | |
| *Total for non-insulation materials* | *19,543* | *0.0252* | *15.3* | *35.6* | *174* |
| *Total for insulation* | *6,953* | *0.000433* | *5.9* | *11.5* | *40.8* |
| *Grand total (materials + insulation)* | *26,496* | *0.0257* | *21.3* | *47.0* | *215* |
| ***Energy*** | | | | | |
| Temperate Oceanic | 61,200 | 0.0080 | 5.25 | 14.1 | 56.6 |
| Temperate Mediterranean | 50,000 | 0.0065 | 4.28 | 11.5 | 46.2 |
| Cool Continental | 145,000 | 0.0189 | 12.42 | 33.4 | 134 |

**Table 4** Characterised data for Part 1, new build: whole house model with PU insulation.

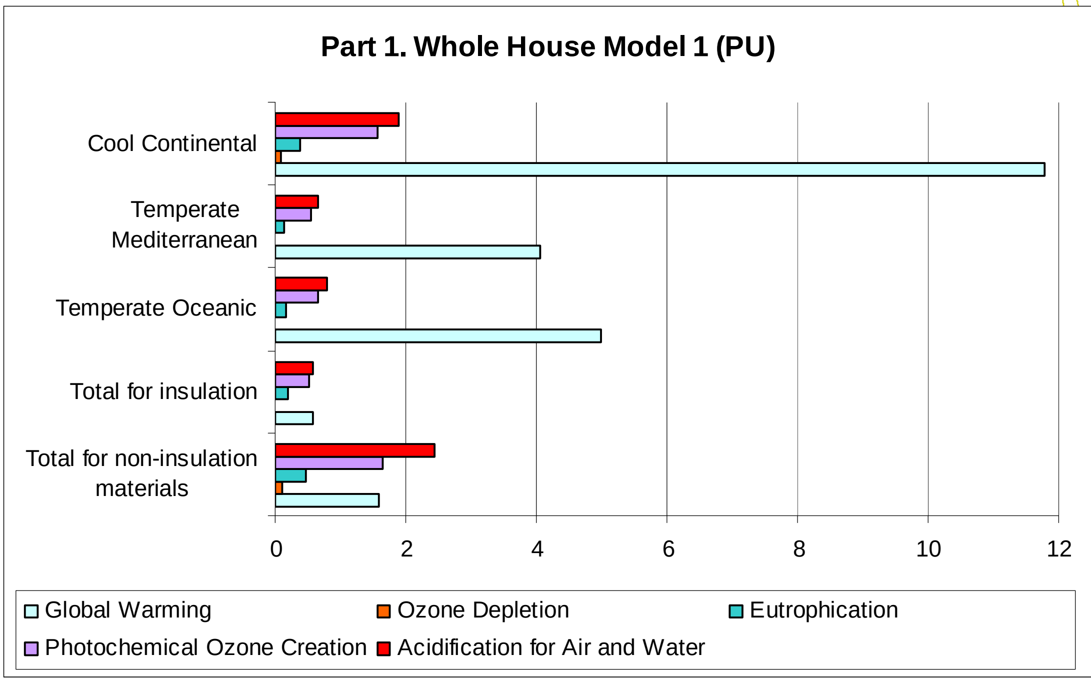



**Figure 7** Part 1 New build whole house model: PU insulation (normalised).

Figure 7 shows that the energy use in all 3 climate zones give the greatest level of Global Warming impact. However, the materials (including the insulation) had higher impacts in Eutrophication, Photochemical Ozone Creation, Acidification for Air and Water and Ozone Depletion for all the climate zones. These results are as expected since natural gas use is not a high contributor to Eutrophication, Ozone Depletion or Acidification for Air and Water.

For Global Warming, the insulation was the source of 26% of the overall materials impact, with the overall materials impact causing 30% (Temperate Oceanic, TO), 35% (Temperate Mediterranean, TM) and 15% (Cool Continental, CC) of the total impact. This finding indicates how the relative importance of the environmental impact of the building's fabric increases as the level of insulation rises and operational heating energy decreases.

The materials were responsible for 58 to 83% of the impacts in Ozone Depletion, Eutrophication, Photochemical Ozone Creation and Acidification for Air and Water.

As expected, in the coldest climate (CC), the impact of energy use was highest.

**Model 2: Stone wool insulation**

Table 5 presents the characterised data for Model 2

| Model 2 | Characterised | | | | |
|---|---|---|---|---|---|
| | **Global Warming** | **Ozone Depletion** | **Eutrophication** | **Photochemical Ozone Creation** | **Acidification for Air and Water** |
| | **kg** | **kg** | **kg** | **kg** | **kg** |
| Wall materials (stone & glass wool insulation) | 8,730 | 0.0117 | 5.71 | 7.05 | 55.4 |
| Stone wool insulation | 2,130 | 0.000400 | 1.06 | 1.05 | 14.1 |
| Extra roof (stone & glass wool insulation) = 3m$^2$ | 82 | 0.000189 | 0.109 | 0.219 | 1.98 |
| Extra foundation (stone & glass wool insulation) = 3m | 574 | 0.000325 | 0.351 | 0.254 | 2.56 |
| roof materials | 1,920 | 0.00332 | 1.90 | 4.26 | 44.2 |
| Stone wool | 2,680 | 0.000502 | 1.33 | 1.31 | 17.8 |
| Ground floor materials | 5,280 | 0.00230 | 2.98 | 2.14 | 23.1 |
| PU (pentane) | 763 | 0.0000484 | 0.65 | 1.24 | 4.48 |
| Upper floor (timber I-joist with chipboard plus plasterboard ceiling below) | 293 | 0.00133 | 1.25 | 1.63 | 22.5 |
| Window (preservative treated, painted softwood, high quality, double glazed) | 3,460 | 0.00670 | 3.57 | 20.60 | 30.2 |
| **Totals** | | | | | |
| *Total for non-insulation materials* | *20,339* | *0.0259* | *15.9* | *36.2* | *180* |
| *Total for insulation* | *5,573* | *0.000950* | *3.0* | *3.6* | *36.4* |
| *Grand total (materials + insulation)* | *25,912* | *0.0269* | *18.9* | *39.8* | *216* |
| ***Energy*** | | | | | |
| Temperate Oceanic | 61,200 | 0.00798 | 5.25 | 14.1 | 56.6 |
| Temperate Mediterranean | 50,000 | 0.00652 | 4.28 | 11.5 | 46.2 |
| Cool Continental | 145,000 | 0.0189 | 12.4 | 33.4 | 134 |

**Table 5** Characterised data for Part 1, new build: whole house model with stone wool insulation

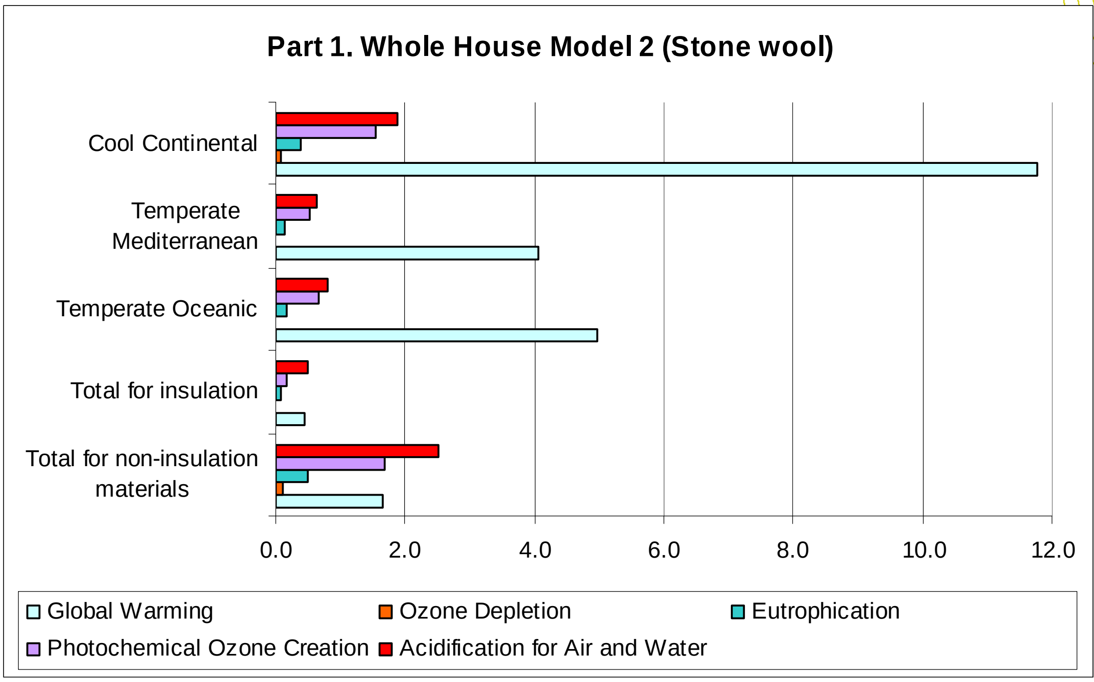



**Figure 8** Part 1 new build whole house model: stone wool insulation (normalised).

The results in Figure 8 again show that energy use had the greatest impact in Global Warming but that the fabric and insulation were the greatest source of Eutrophication, Photochemical Ozone Creation, Acidification for Air and Water and Ozone Depletion for all climate zones.

For Global Warming, the insulation accounted for 22% of the overall materials impact, with the overall materials impact contributing 30% (TO), 35% (TM) and 16% (CC) of the total impact. The materials were the source of 56 to 92% of the total impacts in the remaining four categories.

**Model 3: Glass wool insulation**

Table 6 presents the characterised data for Model 3:

| Model 3 | Characterised | | | | |
|---|---|---|---|---|---|
| | Global Warming | Ozone Depletion | Eutrophication | Photochemical Ozone Creation | Acidification for Air and Water |
| | kg | kg | kg | kg | kg |
| Wall materials (stone & glass wool insulation) | 8,730 | 0.0117 | 5.71 | 7.05 | 55.4 |
| Glass wool insulation | 1,450 | 0.000264 | 0.947 | 1.05 | 5.85 |
| Extra roof (stone & glass wool insulation) = 3m$^2$ | 82 | 0.000189 | 0.109 | 0.219 | 1.98 |
| Extra foundation (stone & glass wool insulation) = 3m | 574 | 0.000325 | 0.351 | 0.254 | 2.56 |
| roof materials | 1,920 | 0.00332 | 1.90 | 4.26 | 44.2 |
| Glass wool | 769 | 0.000140 | 0.502 | 0.557 | 3.10 |
| Ground floor materials | 5,280 | 0.00230 | 2.98 | 2.14 | 23.1 |
| PU (pentane) | 763 | 0.0000484 | 0.65 | 1.24 | 4.48 |
| Upper floor (timber I-joist with chipboard plus plasterboard ceiling below) | 293 | 0.00133 | 1.25 | 1.63 | 22.5 |
| Window (preservative treated, painted softwood, high quality, double glazed) | 3,460 | 0.00670 | 3.57 | 20.60 | 30.2 |
| **Total** | | | | | |
| *Total for non-insulation materials* | *20,339* | *0.0259* | *15.9* | *36.2* | *180* |
| *Total for insulation* | *2,982* | *0.000453* | *2.09* | *2.85* | *13.4* |
| *Grand total (materials + insulation)* | *23,321* | *0.0264* | *18.0* | *39.0* | *193* |
| ***Energy*** | | | | | |
| Temperate Oceanic | 61,200 | 0.00798 | 5.25 | 14.1 | 56.6 |
| Temperate Mediterranean | 50,000 | 0.00652 | 4.28 | 11.5 | 46.2 |
| Cool Continental | 145,000 | 0.0189 | 12.4 | 33.4 | 134 |

**Table 6** Characterised data for Part 1, new build: whole house model with glass wool insulation

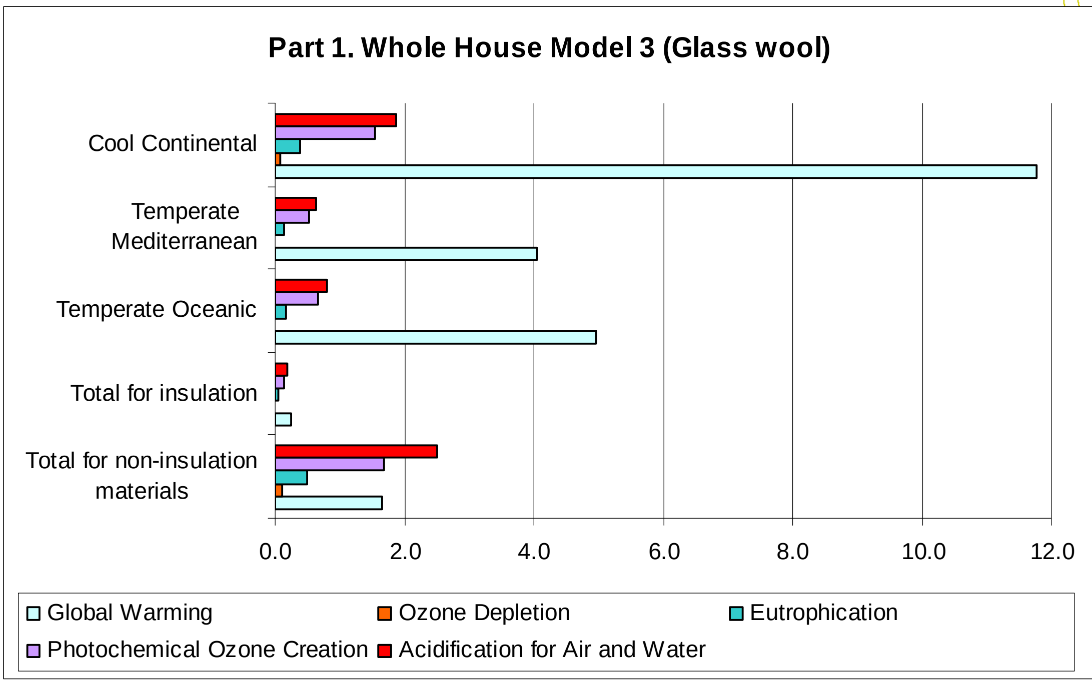



**Figure 9** Part 1, new build whole house model: glass wool insulation (normalised).

As for Models 1 and 2, the greatest amount of Global Warming was for the energy consumption in Model 3 for all climate zones. Again the total material impact was higher than the energy impact for Eutrophication, Photochemical Ozone Creation, Acidification for Air and Water and Ozone Depletion.

The insulation accounted for 13% of the total materials Global Warming impact. Overall materials were the source of 31% (TO), 36% (TM) and 16% (CC) total Global Warming impact. Materials were responsible for 57 to 96% of the total impact in the other four categories.

The following graphs present the characterised data for the three whole house models for each individual impact category.

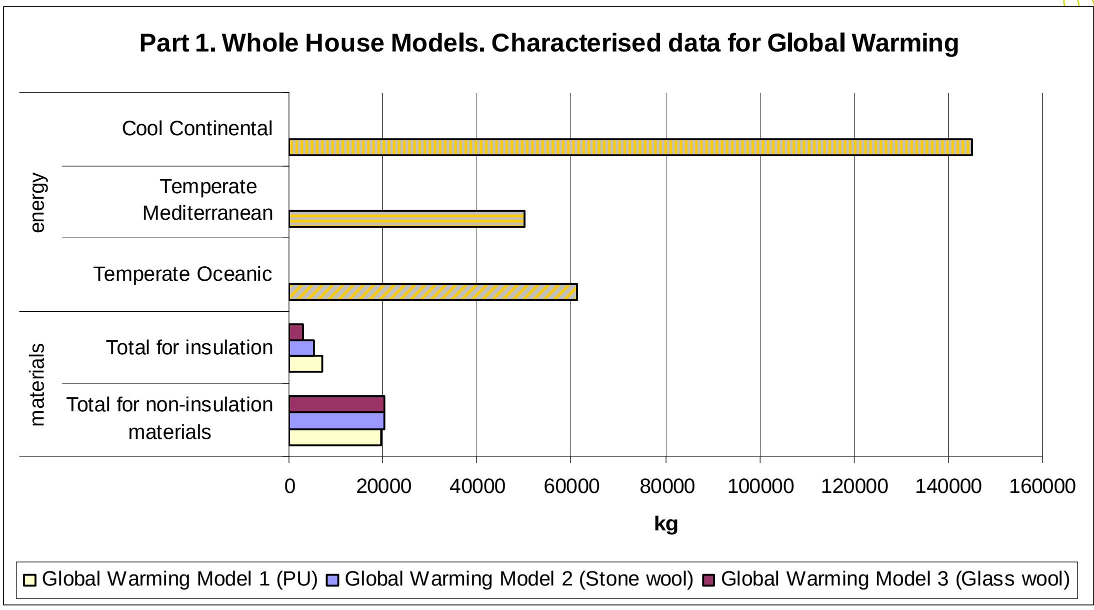



**Figure 10**. Part 1. Whole house models - Global Warming, kg $CO_2$ eq. (100 years) (characterised).

For each climatic zone, the energy use modelled for all three insulation options is the same, as the elements have common U values. The characterised Global Warming results in Figure 10 comparing the three whole house models show that the non-insulation materials' impact was lowest for the PU house (Model 1) but the impact of the PU insulation was larger than for either stone wool of glass wool.

The results also show that the building's materials were responsible for around one third of the total Global Warming impact for the TO and TM climates.

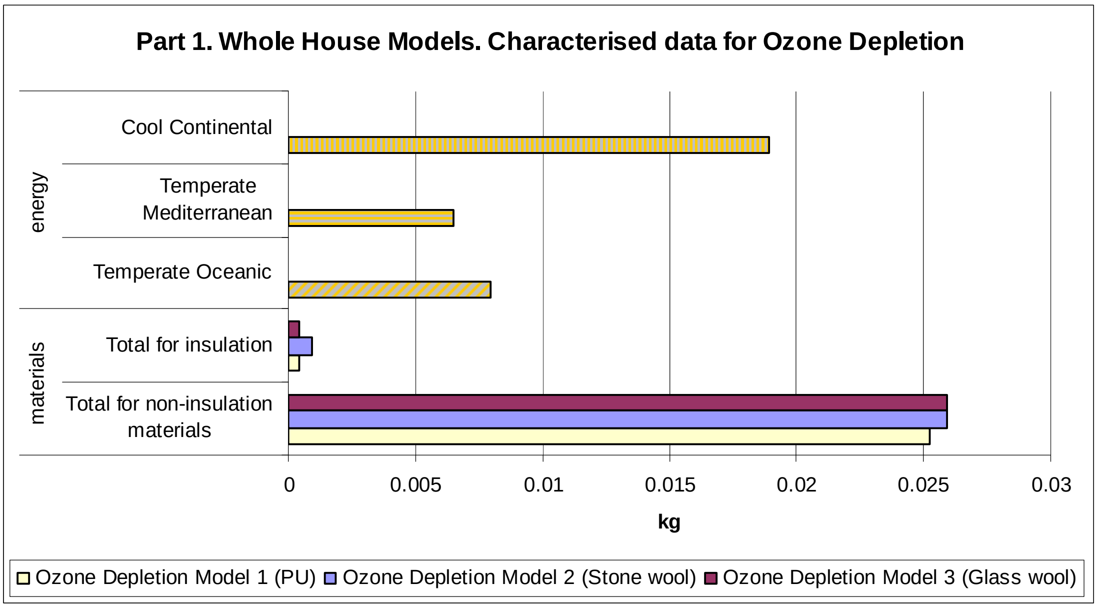



**Figure 11**. Part 1. Whole house models - Ozone Depletion, kg CFC 11 eq. (characterised)

For each climatic zone, the energy use modelled for all three insulation options is the same, as the elements have common U values. The results in Figure 11 for Ozone Depletion show that both the insulation and the non-insulation material impacts for Model 1 (PU) were lower than those for stone wool or glass wool. The combined materials impact was greater than that from energy use for all climate zones for all models.

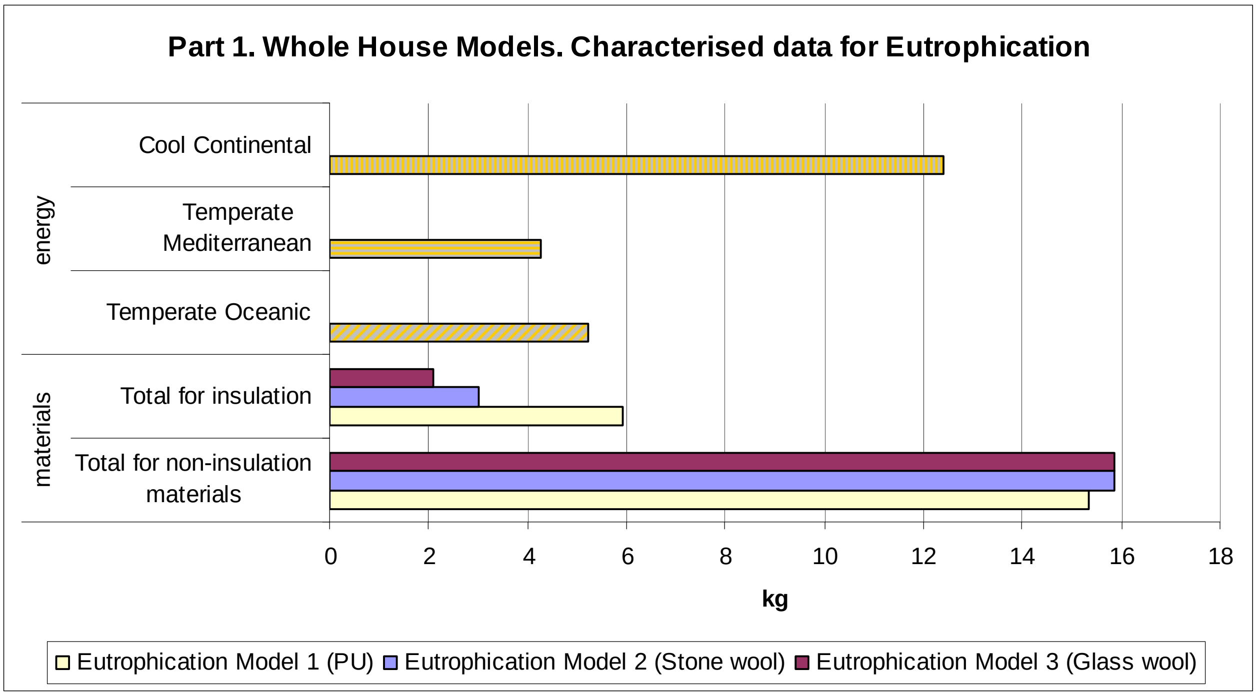



**Figure 12.** Part 1. Whole house models – Eutrophication, $PO_4$ eq. (characterised)

For each climatic zone, the energy use modelled for all three insulation options is the same, as the elements have common U values. The results in Figure 12 for Eutrophication, as for Global Warming, show that the non-insulation material impact for Model 1 was lower than for Models 2 and 3 but the impact for the insulation was higher for Model 1 than either Model 2 or 3. The results also show that the overall materials impact was greater than that for energy use for all 3 climate zones.

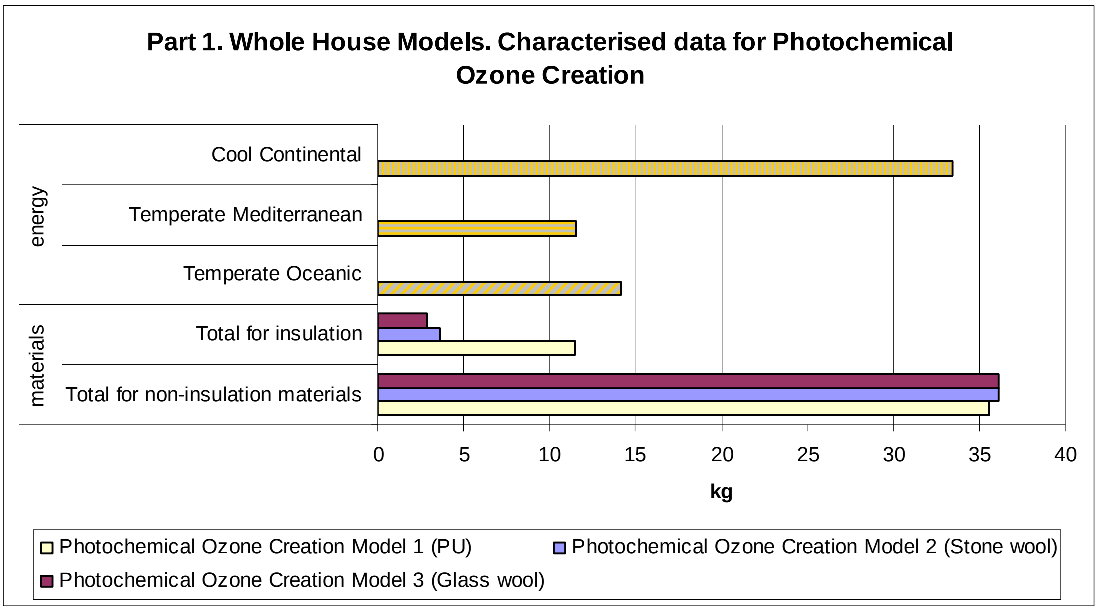



**Figure 13.** Part 1. Whole house models – Photochemical Ozone Creation, kg $C_2H_4$ eq. (characterised)

As for Global Warming and Eutrophication, the non-insulation material Photochemical Ozone Creation impacts for Model 1 were lower than those for Models 2 and 3. Also as for Eutrophication, the total material impacts were greater than those for energy for all 3 climate zones.

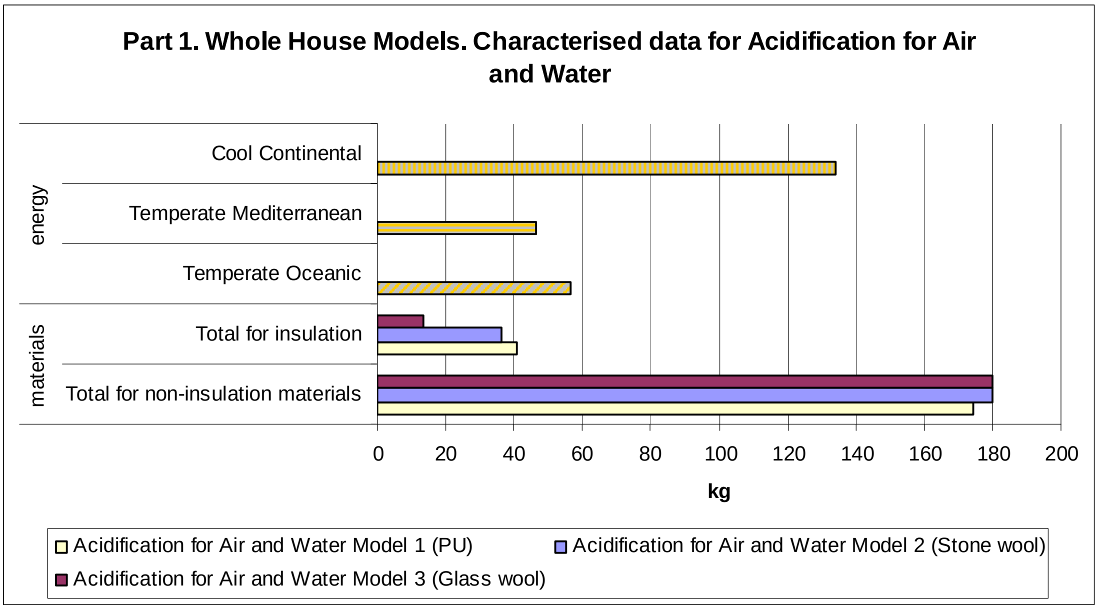



**Figure 14**. Part 1. Whole house models – Acidification for Air and Water, kg $SO_2$ eq. (characterised)

For each climatic zone, the energy use modelled for all three insulation options is the same, as the elements have common U values. Once more, the non-insulation material impacts of Model 1 were less than for Models 2 and 3 but the impact of the insulation in Model 1 was greater than for Models 2 and 3. As for Global Warming, Eutrophication and Photochemical Ozone Creation, the total materials impact was greater than that for energy for all 3 climate zones.

Figure 15 below compares the whole house models for all impact categories by expressing the results for each model relative to the maximum in each category.

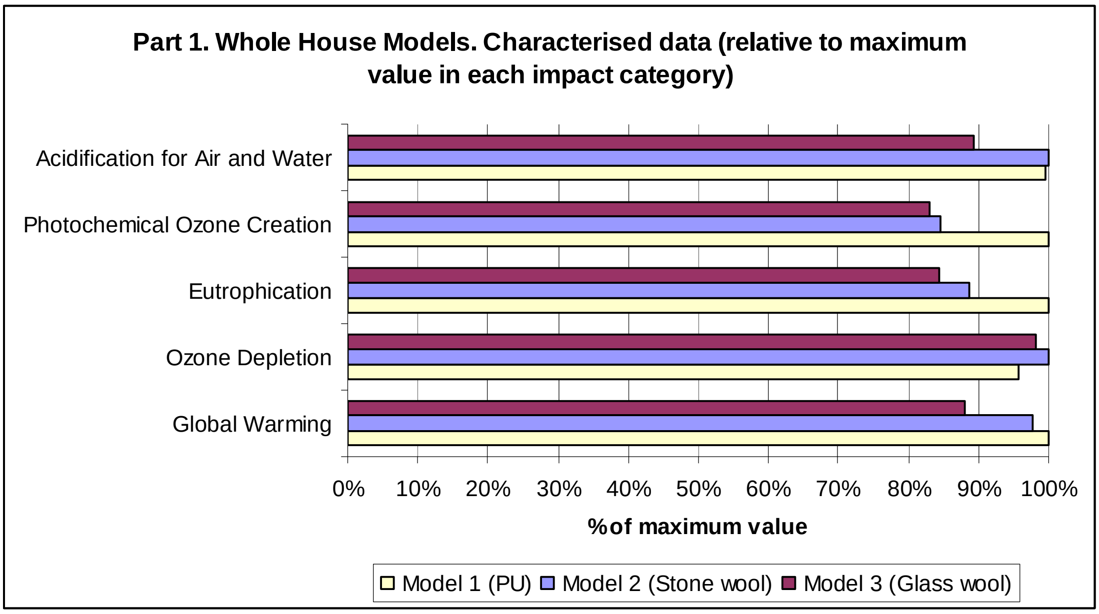



**Figure 15** Part 1. Whole house models - material impacts (characterised)

The results in Figure 15 show that the PU design’s materials had the greatest impact in Global Warming, Eutrophication & Ozone Depletion, the second highest in Photochemical Ozone Creation and the lowest in Ozone Depletion. The difference was typically more than 10% with the greatest differences in Photochemical Ozone Creation (maximum of 17%) and Eutrophication (maximum of 16%). The smallest difference was in Ozone Depletion (4%).

The results presented in Figures 7 to 9 indicate that Ozone Depletion was relatively small compared to background levels for all models.

Combined, these findings show that the overall performance of the whole house models was broadly similar but that the PU design’s materials tended to have greater levels of impact.

## 2.3 Part 2 Refurbishment: internal lining of existing external walls LCA

This assessment has been done on the basis of the materials needed to install the insulation on the inner face of the external wall; the impacts associated with the existing external wall fabric have not been included. The EPS and PU insulation and plasterboard were installed with plaster adhesive whereas the stone wool and glass wool were installed with timber battens, breather membrane and screws to attach the battens to the external wall and the plasterboard to the battens.

Appendix 2 describes the models used for each solution. Table 7 presents the characterised data for the internal lining assessments.

| **Internal Lining (refurbishment)** | | **Characterised** | | | | |
|---|---|---|---|---|---|---|
| | | **Global Warming** | **Ozone Depletion** | **Eutrophication** | **Photochemical Ozone Creation** | **Acidification for Air and Water** |
| | | **kg** | **kg** | **kg** | **kg** | **kg** |
| Installation materials (PU & EPS) | | 1,730 | 0.00162 | 1.237 | 2.725 | 47.905 |
| PU (pentane) | | 1,090 | 0.00007 | 0.895 | 1.699 | 6.432 |
| EPS | | 948 | 0.00007 | 0.300 | 2.038 | 3.361 |
| Installation materials (stone wool & glass wool) | | 1,060 | 0.00160 | 1.112 | 2.444 | 46.317 |
| Stone wool | | 337 | 0.00006 | 0.167 | 0.165 | 2.235 |
| Glass wool | | 323 | 0.00006 | 0.211 | 0.234 | 1.305 |
| **Totals** | | | | | | |
| *Stone wool total (materials + insulation)* | | *1,400* | *0.00166* | *1.28* | *2.61* | *48.6* |
| *Glass wool total (materials + insulation)* | | *1,380* | *0.00166* | *1.32* | *2.68* | *47.6* |
| *PU (pentane) total (materials + insulation)* | | *2,820* | *0.00170* | *2.13* | *4.42* | *54.3* |
| *EPS total (materials + insulation)* | | *2,680* | *0.00170* | *1.54* | *4.76* | *51.3* |
| Energy Temperate Oceanic | PU | 120,000 | 0.0156 | 10.3 | 27.6 | 111 |
| | Stone wool | 135,000 | 0.0176 | 11.6 | 31.1 | 125 |
| | Glass wool | 135,000 | 0.0176 | 11.6 | 31.1 | 125 |
| | EPS | 129,000 | 0.0168 | 11.1 | 29.8 | 119 |
| Energy Temperate Mediterranean | PU | 97,700 | 0.0127 | 8.37 | 22.5 | 90.4 |
| | Stone wool | 110,000 | 0.0144 | 9.46 | 25.5 | 102 |
| | Glass wool | 110,000 | 0.0144 | 9.46 | 25.5 | 102 |
| | EPS | 105,000 | 0.0138 | 9.04 | 24.3 | 97.6 |
| Energy Cool Continental | PU | 252,000 | 0.0329 | 21.6 | 58.2 | 234 |
| | Stone wool | 280,000 | 0.0365 | 24.0 | 64.6 | 259 |
| | Glass wool | 280,000 | 0.0365 | 24.0 | 64.6 | 259 |
| | EPS | 269,000 | 0.0351 | 23.1 | 62.1 | 249 |

**Table 7** Characterised data for Part 2 Refurbishment lining of external walls with glass wool, stone wool, EPS and PU insulation.

The graphs below present the data from Table 7 in graphical form for comparison purposes.

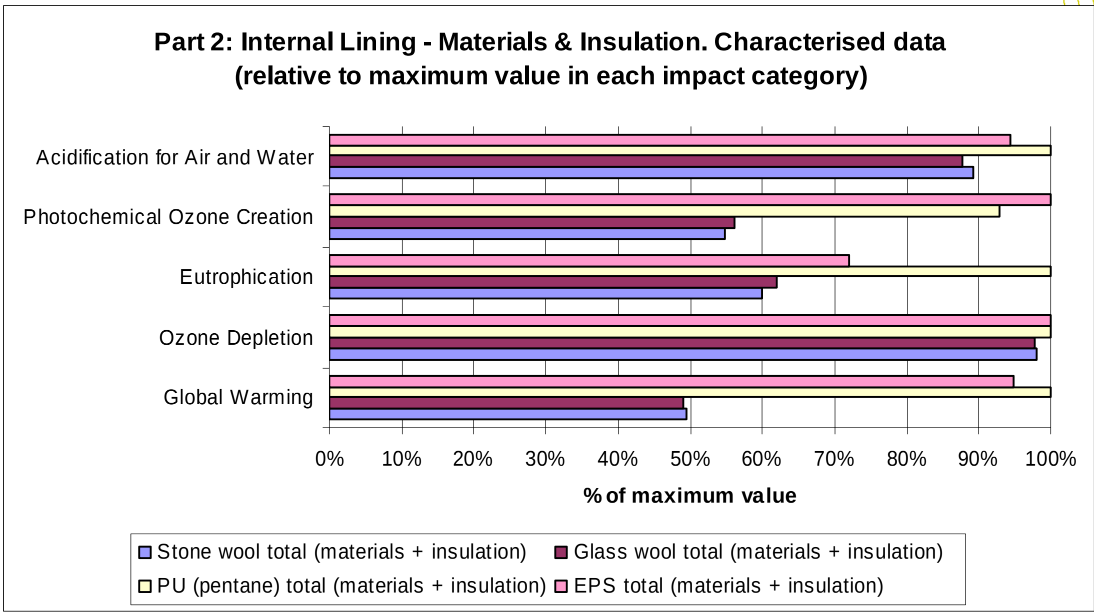
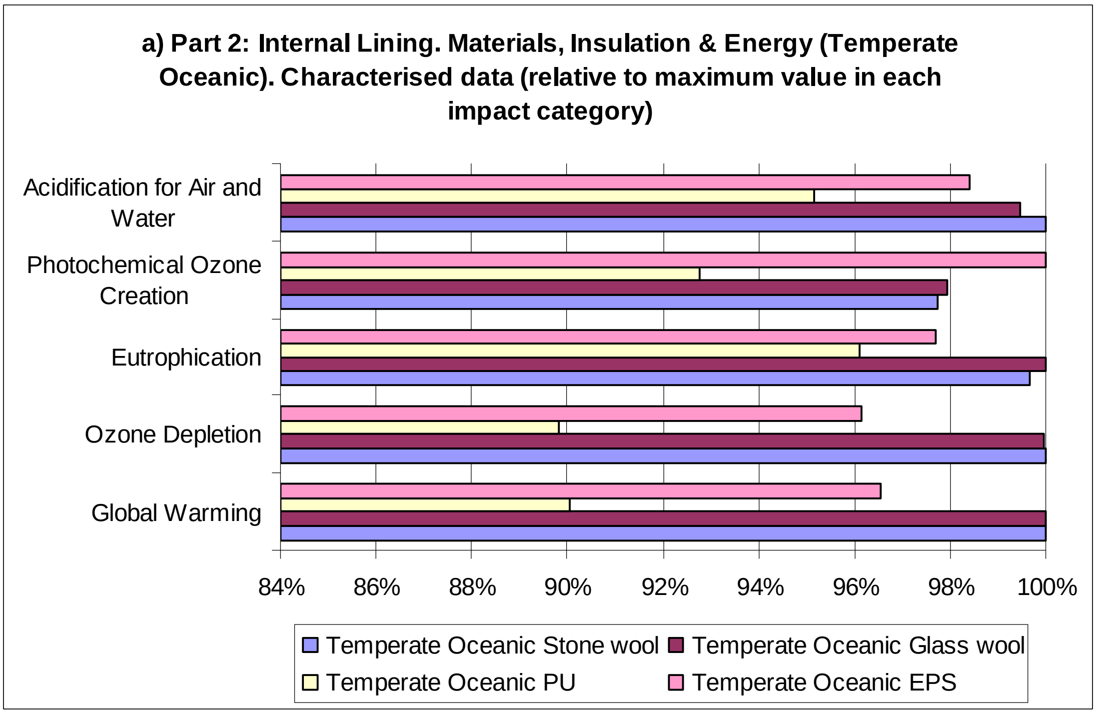
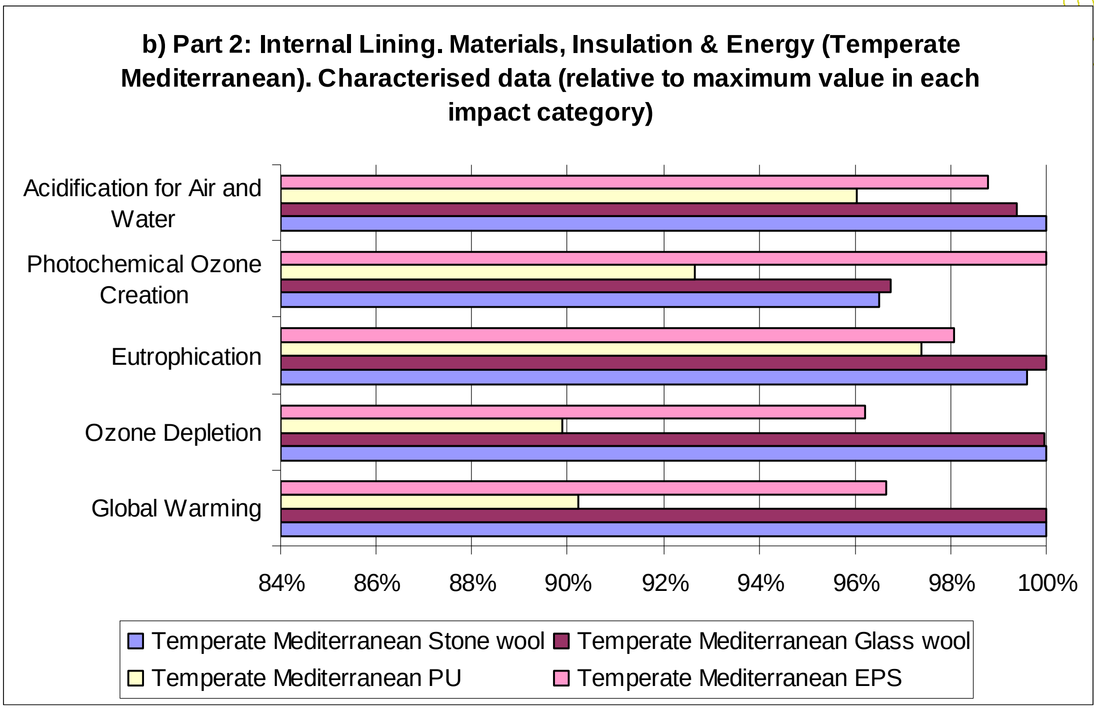



**Figure 16** Part 2 Refurbishment of external walls with glass wool, stone wool, EPS and PU: materials only

The characterised results in Figure 16 show that, in terms of materials usage, the PU insulation solution had the greatest level of impact in the Global Warming, Eutrophication, Acidification for Air and Water, and Photochemical Ozone Creation impact categories. The PU design had the second highest impact in Ozone Depletion.

The graph below compares the impacts from the materials to those from the energy in the three climate zones.





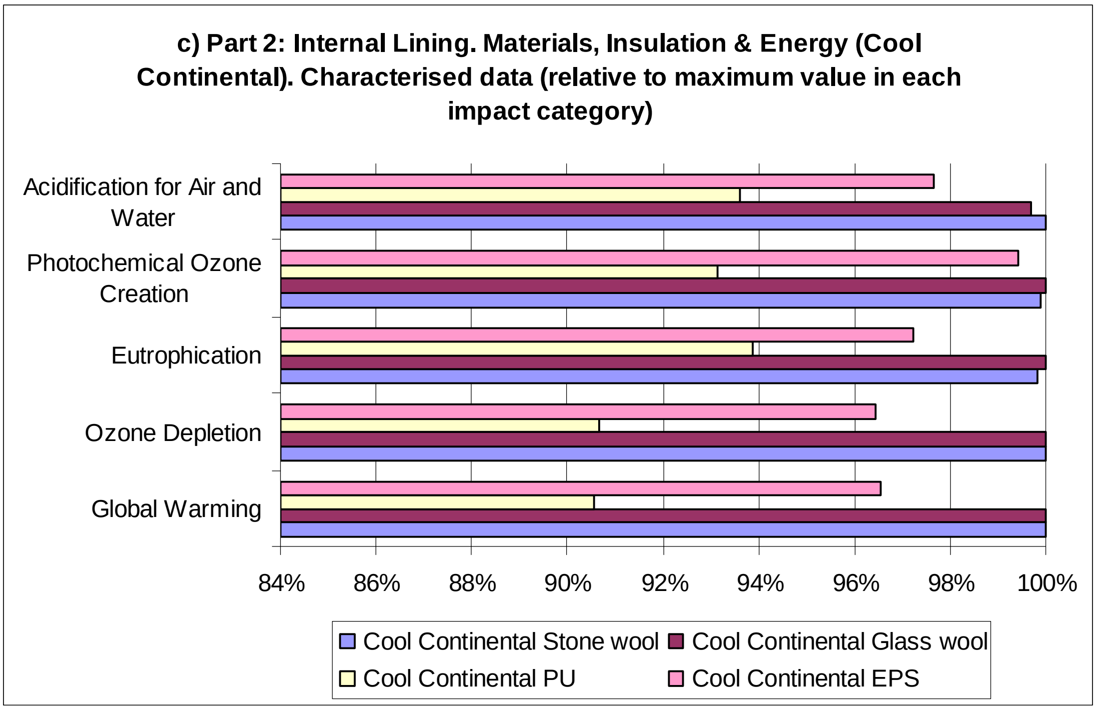
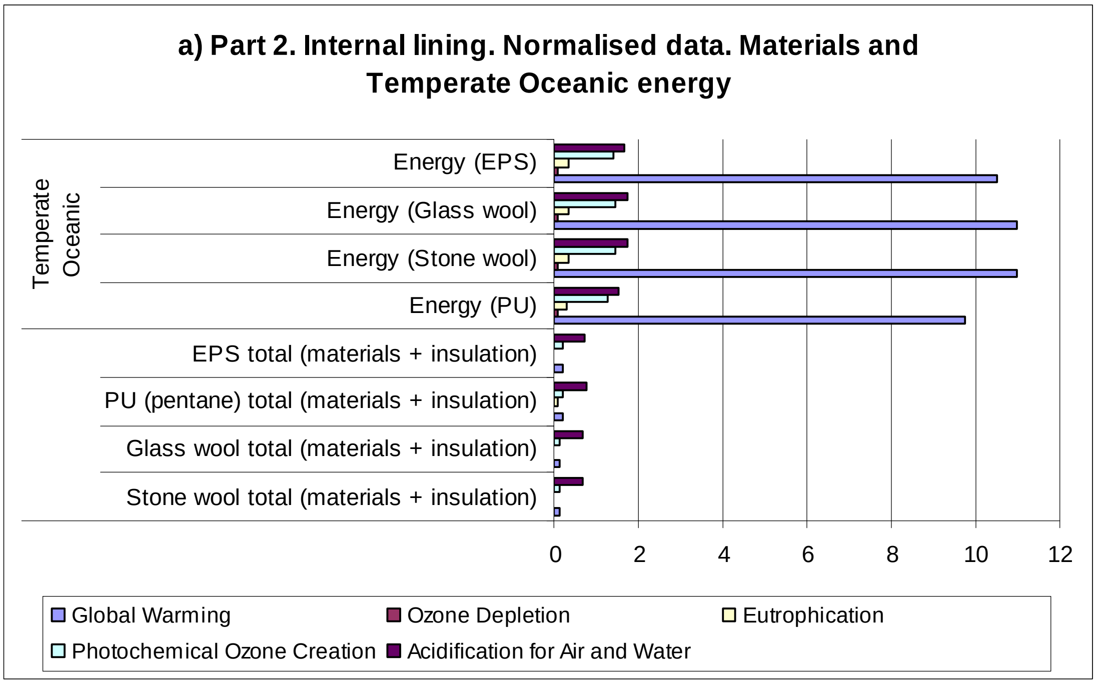
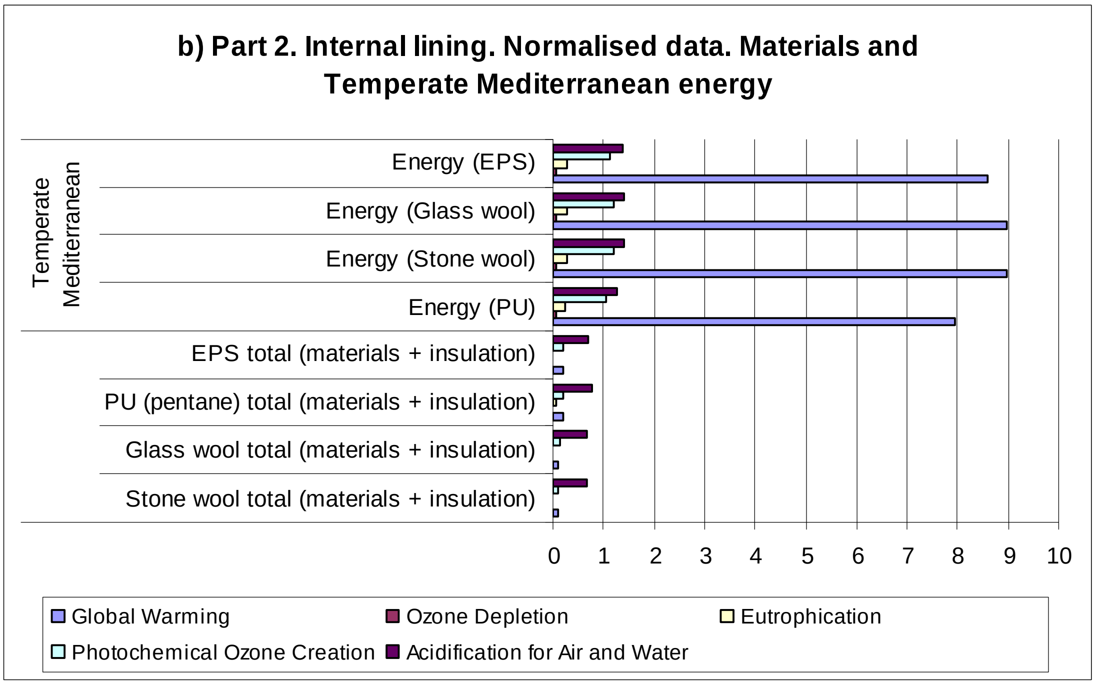




**Figure 17** Part 2, refurbishment of external walls with glass wool, stone wool, EPS and PU. Characterised data: a) Temperate Oceanic; b) Temperate Mediterranean, and c) Cool Continental.

The characterised results in Figure 17 a) to c) show that the PU internal lining gave the lowest total impacts of all the solutions in all climate zones.

For Global Warming, overall, the PU design was around 10% lower than either the stone wool or glass wool designs and at least 5% better than the EPS design.



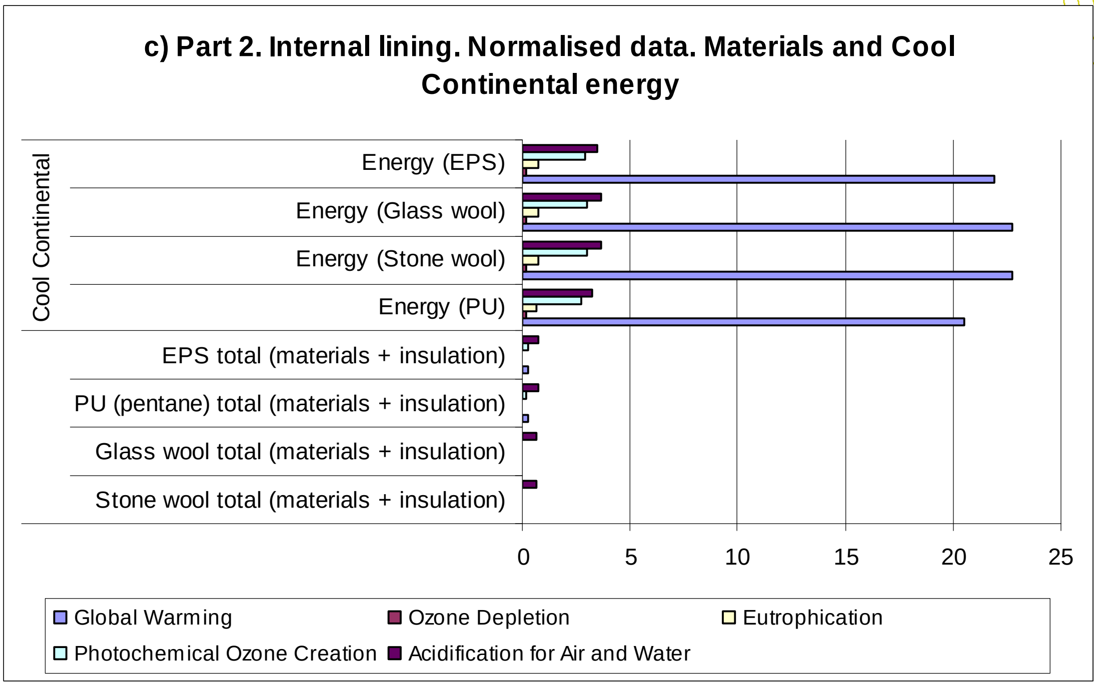



**Figure 18** Part 2, refurbishment of external walls with glass wool, stone wool, EPS and PU: a) Temperate Oceanic, b) Temperate Mediterranean, and c) Cool Continental

The normalised results presented in Figure 18 a) to c) indicate that the greatest impact for each of the internal lining options was Acidification for Air and Water. However, the insulation was responsible for only 3% (glass wool), 5% (stone wool), 7% (EPS) and 12% (PU) for this Acidification for Air and Water impact.

The insulations' contribution to Global Warming of the design was higher: 24% for stone wool; 23% for glass wool; 39% for PU and 35% for EPS. The insulations were the source of 4% of the total material Ozone Depletion. For Eutrophication impacts, the PU was the source of 42% of the total material impact and the EPS 20%; stone wool and glass wool were responsible for around 15% of the total. For Photochemical Ozone Creation, the PU and EPS insulations were the cause of around 40% of the total material impacts, whereas the stone wool and glass wool were responsible for less than 10% of the total material impacts.

## 2.4 Part 3 New warm deck flat roof LCA

Appendix 2 describes the design solutions adopted to achieve the target U-values. Energy has not been modelled as it is assumed to be consistent for all three solutions.

The characterised data for these flat roofs are presented in Table 8.

| Flat roof | Characterised | | | | |
|---|---|---|---|---|---|
| | Global Warming | Ozone Depletion | Eutrophication | Photochemical Ozone Creation | Acidification for Air and Water |
| | kg | kg | kg | kg | kg |
| Flat roof materials | -310 | 0.00313 | 1.28 | 2.31 | 24.3 |
| PU (pentane) | 1,450 | 0.0000896 | 1.24 | 2.40 | 8.49 |
| Stone wool | 2,980 | 0.000560 | 1.48 | 1.46 | 19.8 |
| EPS | 2,310 | 0.000178 | 0.731 | 4.96 | 8.19 |
| **Totals** | | | | | |
| *Stone wool total (materials + insulation)* | *2,670* | *0.00369* | *2.76* | *3.78* | *44.1* |
| *PU (pentane) total (materials + insulation)* | *1,140* | *0.00322* | *2.52* | *4.71* | *32.8* |
| *EPS total (materials + insulation)* | *2,000* | *0.00331* | *2.01* | *7.28* | *32.5* |

**Table 8** Characterised data for Part 3, warm deck flat roof with stone wool, EPS and PU insulation.

The following graph summarises the characterised data set out in Table 8.

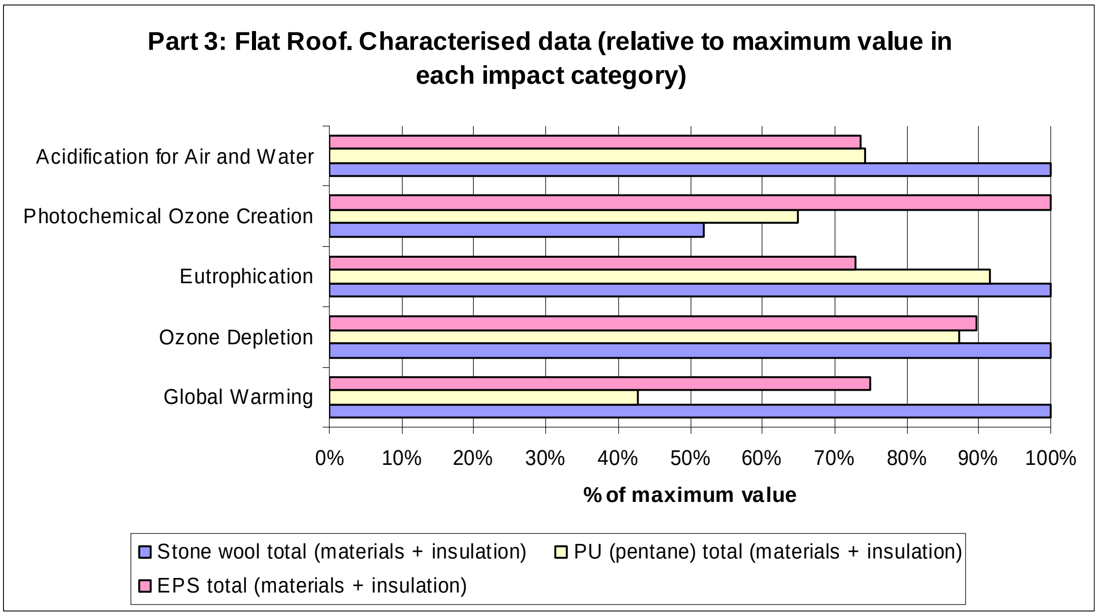



**Figure 19**. Part 3, warm deck flat roof with stone wool, EPS and PU insulation (characterised).

Figure 19 shows that the PU option was never the highest level of impact for any category; it was the lowest for Global Warming and Ozone Depletion. The PU option was second lowest for Eutrophication, Photochemical Ozone Creation and Acidification for Air and Water.

From Table 8, it can be seen that the flat roof materials achieved an overall negative (i.e. beneficial) Global Warming due to the carbon sequestered in the structure's timber (joists and decking). Consequently, the insulation materials were solely responsible for the damaging Global Warming impacts. The insulations were responsible for 3 to 15% of the overall impacts for Ozone Depletion, and between 25 and 68% of the total Eutrophication, Photochemical Ozone Creation and Acidification for Air and Water.

The graph below shows the normalised impacts of the roofing materials and the insulations in each design.

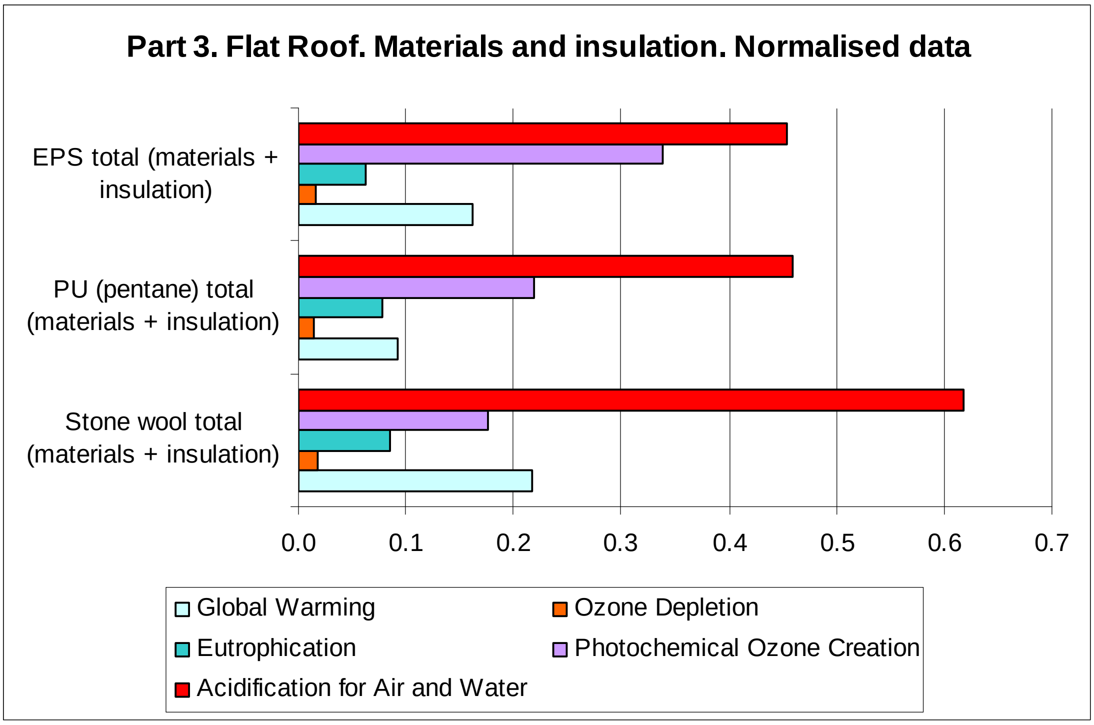



**Figure 20** Part 3, warm deck flat roof with stone wool, EPS and PU insulation (normalised).

The normalised data in Figure 20 shows that the Acidification for Air and Water impact category was the largest for all of the solutions, followed by Photochemical Ozone Creation for the PU and EPS, and Global Warming for the stone wool. Ozone Depletion was the smallest relative impact for all solutions.

### Comments on sensitivity of assumptions

The results presented here are influenced by the assumptions and decisions made during the analysis. The key assumptions that are likely to affect the findings are:

- Polyurethane (PU) insulation is pentane-blown - HFC-blown PU would have much greater environmental impacts;
- The modelled constructions are common and relevant for all climate zones studied;
- Energy source is natural gas;

- Space heating only is modelled; other energy use in the house, for lighting, domestic hot water and other electrical demand is not assumed to alter depending on location or insulation type;
- U-values for modelled new build elements are lower than for English building regulations (i.e. an improvement) meaning that the modelled designs use less energy than would be the case for current UK practice. This results in materials having an increased relative importance in overall building impact. Conversely, for the refurbishment assessment, the U-values of the walls are, with the exception of the PU, much lower than required by English building regulations for refurbishment for change of use (i.e. a deterioration) resulting in greater energy use than would be expected;
- PU insulation is disposed of 90% to landfill and 10% to incineration, based on UK practice. If PU was predominantly incinerated, it would have higher climate change impacts and lower POCP impacts, and slightly lower acidification impacts from disposal.

# 3 Identification of cost impacts

The purpose of this section of the report is to present the findings of the life cycle cost study undertaken. It provides a brief introduction to life cycle costing, and details the methodology adopted for the study. The results of the study are presented in both graphical and tabular format for ease of interpretation.

## 3.1 Introduction to LCC

Life cycle costing is a technique to establish the total cost of ownership. It is a structured approach which addresses all the elements of this cost and can be used to produce a spend profile of the asset over its anticipated life-span. The results of life cycle cost analysis can be used to assist in the decision-making process when there is a choice of product and provides the opportunity to optimise the allocation of benefits and costs to achieve “best value”.

For convenience these costs are usually considered under three headings

- Initial Cost
- Operational Costs
- Disposal Costs if applicable

**Definition of Life Cycle Costs (LCC)**

A life cycle cost is defined in ISO 15686 Part 5[7] as follows:

- Cost of an asset or its parts throughout its life cycle, while fulfilling the performance requirements

The use of life cycle costing presents a powerful tool to deliver economic sustainability within the construction industry and encourages the use of "Best Value" design solutions.

Life cycle cost modelling provides a *“rationale for choice in circumstances where there are alternative means of achieving a given object and where those alternatives differ not only in their initial costs, but also in subsequent operational costs”* (Seeley, 1996). The purpose of life cycle costing is to improve decisions regarding capital investment and the related future costs required to operate a built asset. It is a tool that can be used by various practitioners to aid the investment decision making process. Life cycle costing techniques aim to optimise decisions on designs, specifications for independent and interdependent building systems so as to ensure initial capital and through life expenditures, which often absorb large amounts of cash, are optimised.

**Financial criteria**

The LCC analysis requires that year on year cash flows are discounted to reflect the time value of money. The year on year cash flows (periodic money streams that are expected to continue in the future) are discounted to account for the fact that these monies will be worth less in the future than they are today. When the monies are discounted they are expressed as present values.

[7] ISO 15686-5 2008 Buildings and constructed assets - Service-life planning -Part 5: Life-cycle costing

In order to compute present values, it is necessary to discount future costs (and hence benefits). Discounting reflects the time value of money. As a result of discounting, benefits and costs are worth more if they are experienced sooner. The higher the discount rate, the lower is the present value of future cash flows.

$$X/(1+r)^{n}$$

*When*

*X= input value*

*r = rate of interest or discount rate*

*n = number of years*

**Figure 21** Discount equation to allow for the time value of money (HM Treasury 1997)

**Assumptions and other considerations**

We have identified repair and maintenance activities for each specification, and identified a cost to carry out the task. This cost data has utilised the BMI Building Maintenance Price Book (2009 edition)[8], Spons or other price books, manufacturers and installers information and BRE data.

During the 50 year study period, maintenance operations for the elements include internal redecoration, brickwork repointing and replacing single ply roof finish to the flat roof. Costs also have allowances for associated waste, labour, overheads and profit.

**Estimated service life**

The estimated service lives are taken from BLP Component Life Manual (CLM), which attaches ‘insured lives’ on an extensive list of components. It is important to note that the Component Life Manual[9] has a range of insured lives for each component. Generally, the service life of a component can be assumed to be the insured life + 20%. In this study we have referenced the insured life that meets the relevant British Standard, meets our maintenance assumptions, and is either the highest or second highest service life prediction. The publication also highlights the factors that may affect their deterioration or failure. We have compared these with the expected lives as published by the Building Cost Information Service (BCIS) of the Royal Institution of Chartered Surveyors. This publication presents a survey of the life expectancies of common building components. For the purposes of this exercise, we have used the data from the CLM as it appears to provide a realistic average of all the sources available and indicates service lives for all components in the situations in which they are used in excess of 50 years, which is the limit of this study. The exceptions to this are the single ply flat roof membrane and decorations to the plaster or plasterboard finish.

[8] BCIS, BMI Building Maintenance Price Book: 2009 Edition, Building Cost Information Service
[9] Building Life Plans Component Life Manual available on line by subscription.

**Discount rates used**

A discount rate of 3.5%, in real terms, reflects the cost to taxpayers of a loan and is the current discount rate used by the UK Treasury.

**The Life Cycle Costs study**

The LCC study has been a non-test based assessment on the durability of the building components, based on BRE's own assumptions, and supported by published material where possible.

**Cost items considered**

The LCC study considers those costs in-use (capital costs of components + installation costs + cost of replacement parts and their installation + maintenance costs) identified by BRE.

The specification for the elements and the cost of all components are intended to represent the typical cost incurred by building owners. The values in the assessment are based on those required for a two storey detached property with a gross internal floor area of $104m^2$.

**Setting the study period**

The study period is the time over which the LCC model is considered. It should be sufficiently long to ensure that a correct assessment of the long-run economic performance can be made. The study period chosen for this assessment is 50 years, which is considered a long enough time scale to assess the long term economic benefits that may be achieved. The 50 year study period does not assume that the building will be demolished at that point in time but will continue in use.

**Capital replacements**

If the service life of an element is less than the LCC study period a replacement of this item is necessary. The model assumes planned replacements of component parts when the life expectancy is less than the LCC study period.

**Variation in discount rate**

The discount rate has been varied to assess the impact on the results of different values. The results of the LCC analysis have been presented for discount rates of 0% and 5% as well as at the base case of 3.5% to show the LCC of the products should the cost of future money flows be different to that assumed. The following graph demonstrates the effect of applying different discount rates on the forecast of a typical future expenditure.

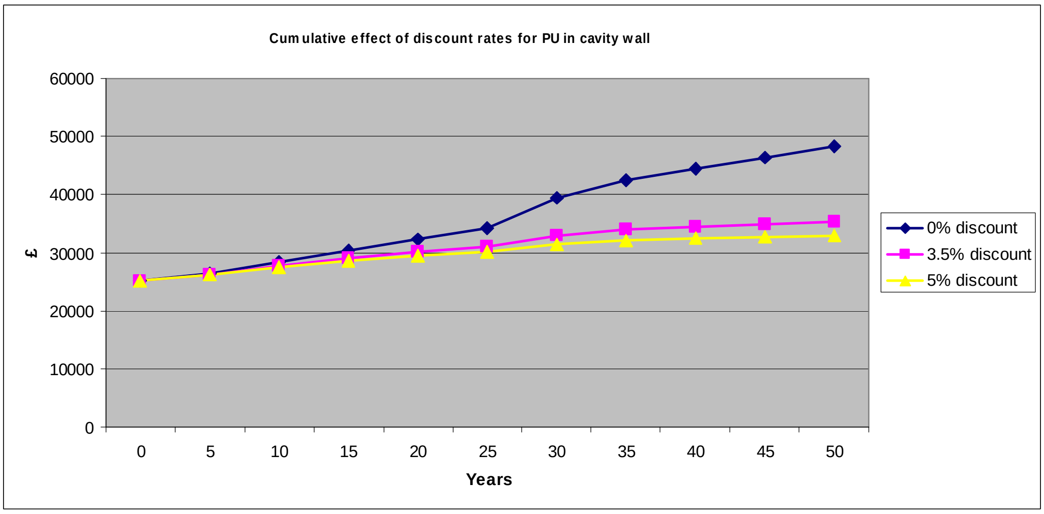



**Figure 22** Cumulative effect of different discount rates for PU insulation in cavity wall for Temperate Oceanic climate zone

### Initial capital costs

We have undertaken a review of published prices for the various component specifications. We have also used data obtained from Spons Architects and Builders Price book and other published price book data. Figures are based upon costs prevailing in September 2009.

### Cost basis

All costs are based on rates current in September 2009 and include general preliminaries, profit and overheads but exclude fees and VAT.

All tables and graphs show the cumulative costs over the study period.

### Energy Costs

In order to be able to make a direct comparison of energy costs for all 3 climatic regions, natural gas prices in the UK have been used in order to provide consistency.

Current prices of natural gas in the UK as charged by British Gas at September 2009, are as follows:

Tier 1 (first 2680 kwh/pa) = 7.206p / kwh

Tier 2 (all subsequent kwh/pa) = 3.457p / kwh

These prices have been used throughout each climate zone.

## 3.2 Part 1 New build LCC

### LCC New cavity wall

The new cavity wall includes half brick thick (102.5mm) outer skin of facing bricks, inner skin of 100mm thick dense blocks, 13mm lightweight plaster with 2 coats of emulsion paint. Cavity insulation materials and thicknesses vary as required in order to achieve the target U value.

In order to maintain a consistent internal floor area, different cavity insulation thicknesses that are required to achieve a common U value of 0.15 $W/m^2 K$ will mean that the overall thickness of external wall varies and the quantity of brickwork in the outer skin will increase. This increase in material has been allowed for in the various life cycle cost analyses for each insulation type. Also, thicker external walls will mean that the total roof and foundation areas will increase and costs relating to this increase are included in each wall insulation calculation. For example, a wall with 270mm cavity insulation means that the property will have an additional 8.00sq m of roof area including soffit overhang and 7.00sq m additional foundation area when compared to a property with a 50mm cavity

Energy costs are included in this section.

Insulation materials for the different scenarios included in this section are as follows:

180mm thick polyurethane; density 32kg/$m^3$; k-value of 0.023

270mm thick stone wool; density 39kg/$m^3$; k-value of 0.037

270mm thick glass wool; density 17kg/$m^3$; k-value of 0.037

The following life cycle costs have been included - internal redecorations (5 years), replace rainwater goods and fascias and repoint brickwork (30 years) and annual energy consumed in each climatic region. (For energy calculations, see Appendix A).

**Part 1 New Cavity Wall: Temperate Oceanic**

| Temp Ocean Discount % | year 0% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 180mm Polyurethane insulation | | 25,211 | 26,515 | 28,493 | 30,470 | 32,448 | 34,426 | 39,725 | 42,873 | 44,850 | 46,828 | 48,806 |
| 270mm Stone wool insulation | | 26,636 | 27,940 | 29,918 | 31,895 | 33,873 | 35,850 | 41,238 | 44,416 | 46,393 | 48,371 | 50,348 |
| 270mm Glass wool insulation | | 26,567 | 27,871 | 29,849 | 31,826 | 33,804 | 35,781 | 41,169 | 44,346 | 46,324 | 48,302 | 50,279 |

| Temp Ocean Discount % | year 3.5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 180mm Polyurethane insulation | | 25,211 | 26,389 | 27,928 | 29,224 | 30,316 | 31,234 | 33,192 | 34,246 | 34,794 | 35,256 | 35,645 |
| 270mm Stone wool insulation | | 26,636 | 27,814 | 29,353 | 30,649 | 31,740 | 32,659 | 34,648 | 35,712 | 36,261 | 36,722 | 37,111 |
| 270mm Glass wool insulation | | 26,567 | 27,744 | 29,284 | 30,580 | 31,671 | 32,590 | 34,579 | 35,643 | 36,192 | 36,653 | 37,042 |

| Temp Ocean Discount % | year 5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 180mm Polyurethane insulation | | 25,211 | 26,340 | 27,728 | 28,815 | 29,666 | 30,334 | 31,625 | 32,293 | 32,614 | 32,865 | 33,062 |
| 270mm Stone wool insulation | | 26,636 | 27,765 | 29,152 | 30,239 | 31,091 | 31,758 | 33,070 | 33,744 | 34,065 | 34,317 | 34,514 |
| 270mm Glass wool insulation | | 26,567 | 27,696 | 29,083 | 30,170 | 31,022 | 31,689 | 33,001 | 33,675 | 33,996 | 34,248 | 34,445 |

**Table 9** LCC new cavity wall: Temperate Mediterranean

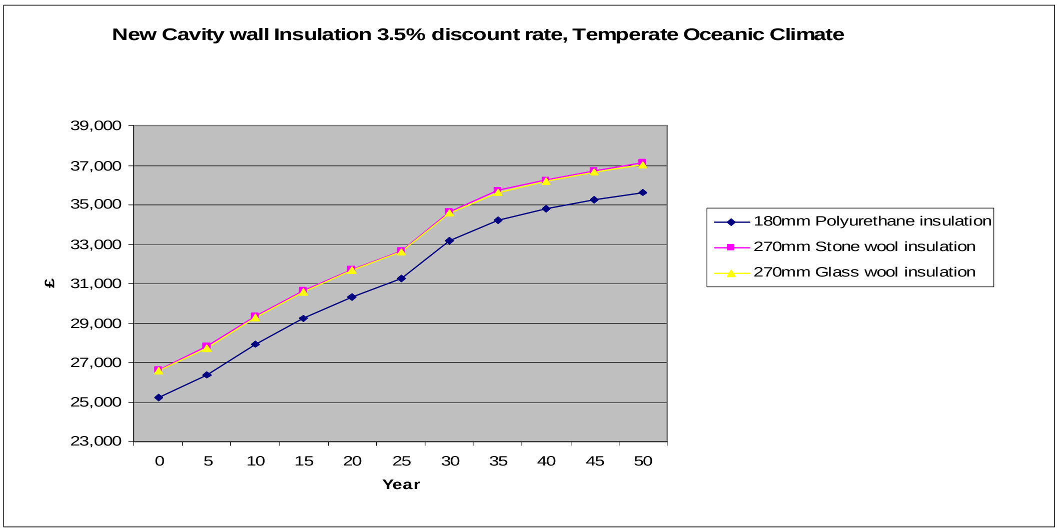



**Figure 23** LCC new Cavity wall: Temperate Oceanic

## Conclusion

180mm polyurethane insulation used in the cavity has the lowest life cycle cost in the Temporary Oceanic climate zone, followed by 270mm glass wool and 270mm stone wool.

**Part 1 New Cavity Wall: Temperate Mediterranean**

| Temp. Med. Discount % | year 0% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 180mm Polyurethane insulation | | 25,211 | 26,368 | 28,199 | 30,029 | 31,860 | 33,690 | 38,843 | 41,843 | 43,674 | 45,504 | 47,335 |
| 270mm Stone wool insulation | | 26,636 | 27,793 | 29,623 | 31,454 | 33,284 | 35,115 | 40,355 | 43,386 | 45,216 | 47,047 | 48,877 |
| 270mm Glass wool insulation | | 26,567 | 27,724 | 29,554 | 31,385 | 33,215 | 35,046 | 40,286 | 43,317 | 45,147 | 46,978 | 48,808 |

| Temp. Med. Discount % | year 3.5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 180mm Polyurethane insulation | | 25,211 | 26,256 | 27,683 | 28,885 | 29,897 | 30,750 | 32,650 | 33,657 | 34,166 | 34,594 | 34,955 |
| 270mm Stone wool insulation | | 26,636 | 27,681 | 29,108 | 30,310 | 31,322 | 32,174 | 34,107 | 35,124 | 35,632 | 36,061 | 36,421 |
| 270mm Glass wool insulation | | 26,567 | 27,612 | 29,039 | 30,241 | 31,253 | 32,105 | 34,038 | 35,055 | 35,563 | 35,992 | 36,352 |

| Temp. Med. Discount % | year 5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 180mm Polyurethane insulation | | 25,211 | 26,213 | 27,500 | 28,509 | 29,300 | 29,919 | 31,173 | 31,811 | 32,109 | 32,342 | 32,525 |
| 270mm Stone wool insulation | | 26,636 | 27,638 | 28,925 | 29,934 | 30,725 | 31,344 | 32,618 | 33,263 | 33,561 | 33,794 | 33,977 |
| 270mm Glass wool insulation | | 26,567 | 27,569 | 28,856 | 29,865 | 30,655 | 31,275 | 32,549 | 33,194 | 33,492 | 33,725 | 33,908 |

**Table 10** LCC new cavity wall: Temperate Mediterranean

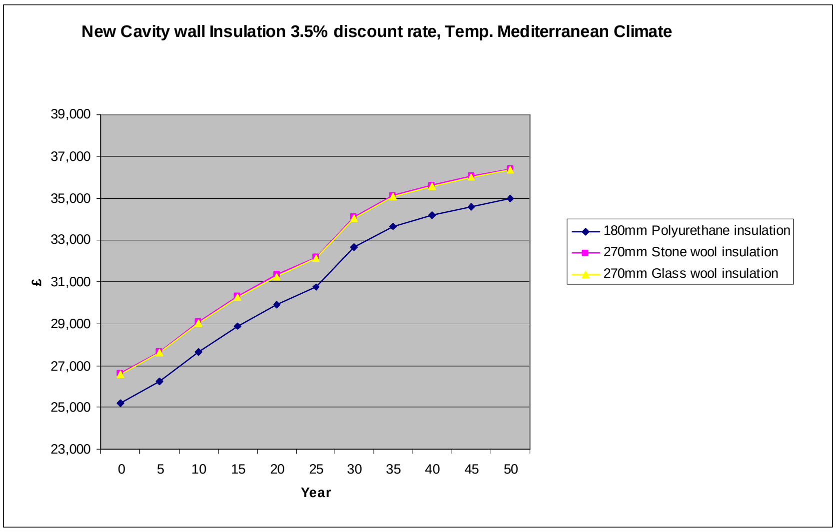



**Figure 24** LCC new cavity wall: Temperate Mediterranean

## Conclusion

180mm polyurethane insulation used in the cavity has the lowest life cycle cost in the Temperate Mediterranean climate zone, followed by 270mm glass wool and 270mm stone wool.

**Part 1 New Cavity Wall: Cool Continental**

| Cool Cont. Discount % | year 0% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 180mm Polyurethane insulation | | 25,211 | 27,612 | 30,687 | 33,762 | 36,837 | 39,912 | 46,309 | 50,554 | 53,628 | 56,703 | 59,778 |
| 270mm Stone wool insulation | | 26,636 | 29,037 | 32,112 | 35,187 | 38,262 | 41,337 | 47,822 | 52,096 | 55,171 | 58,246 | 61,321 |
| 270mm Glass wool insulation | | 26,567 | 28,968 | 32,043 | 35,118 | 38,193 | 41,268 | 47,752 | 52,027 | 55,102 | 58,177 | 61,252 |

| Cool Cont. Discount % | year 3.5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 180mm Polyurethane insulation | | 25,211 | 27,380 | 29,753 | 31,752 | 33,434 | 34,851 | 37,228 | 38,635 | 39,481 | 40,193 | 40,792 |
| 270mm Stone wool insulation | | 26,636 | 28,804 | 31,178 | 33,177 | 34,859 | 36,276 | 38,684 | 40,101 | 40,947 | 41,659 | 42,259 |
| 270mm Glass wool insulation | | 26,567 | 28,735 | 31,109 | 33,107 | 34,790 | 36,207 | 38,615 | 40,032 | 40,878 | 41,590 | 42,189 |

| Cool Cont. Discount % | year 5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 180mm Polyurethane insulation | | 25,211 | 27,290 | 29,422 | 31,092 | 32,401 | 33,427 | 34,999 | 35,886 | 36,379 | 36,766 | 37,068 |
| 270mm Stone wool insulation | | 26,636 | 28,715 | 30,847 | 32,517 | 33,826 | 34,851 | 36,444 | 37,338 | 37,831 | 38,217 | 38,520 |
| 270mm Glass wool insulation | | 26,567 | 28,646 | 30,778 | 32,448 | 33,757 | 34,782 | 36,375 | 37,269 | 37,762 | 38,148 | 38,451 |

**Table 11** LCC new cavity wall: Cool Continental

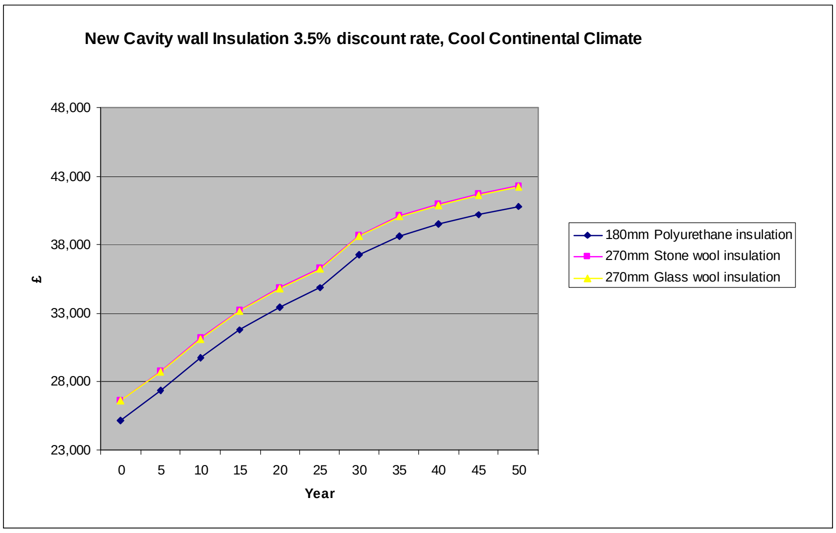



**Figure 25** LCC new cavity wall: Cool Continental.

## Conclusion

180mm polyurethane insulation used in the cavity has the lowest life cycle cost in the Cool Continental climate zone, followed by 270mm glass wool and 270mm stone wool.

**LCC New pitched roof**

The new pitched roof includes a softwood attic trussed rafter 45degree pitched roof with concrete interlocking tiles, underfelt, battens, eaves and ridges, plasterboard ceiling with 2 coats of emulsion paint. Insulation materials and thicknesses vary as required in order to achieve the target U value. Standard external walls with 50mm cavity have been assumed for all insulation types.

Insulation materials for the different scenarios included in this section are as follows:

190mm thick polyurethane comprising 100mm between the rafters and 90mm across the rafters; density 32kg/m$^3$; k-value of 0.023

310mm thick stone wool comprising 220mm between the rafters and 90mm across the rafters; density 45kg/m$^3$ between the rafters and 145kg/m$^3$ across the rafters; k-value of 0.038

300mm thick glass wool fixed between the rafters and battens; density 17kg/m$^3$; k-value of 0.032

The following life cycle costs have been included - internal redecorations (5 years).

| Part 1 New Pitched Roof Slopes: Temperate Oceanic | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp Ocean Discount % | year 0% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 190mm Polyurethane insulation | | 12,865 | 12,865 | 13,137 | 13,409 | 13,681 | 13,953 | 14,224 | 14,496 | 14,768 | 15,040 | 15,312 |
| 310mm Stone wool insulation | | 16,324 | 16,324 | 16,596 | 16,868 | 17,140 | 17,412 | 17,684 | 17,956 | 18,228 | 18,500 | 18,772 |
| 300mm Glass wool insulation | | 16,154 | 16,154 | 16,426 | 16,698 | 16,970 | 17,242 | 17,514 | 17,786 | 18,058 | 18,330 | 18,602 |
| Temp Ocean Discount % | year 3.5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 190mm Polyurethane insulation | | 12,865 | 12,865 | 13,086 | 13,272 | 13,429 | 13,561 | 13,672 | 13,766 | 13,845 | 13,911 | 13,967 |
| 310mm Stone wool insulation | | 16,324 | 16,324 | 16,546 | 16,732 | 16,889 | 17,021 | 17,132 | 17,226 | 17,304 | 17,371 | 17,427 |
| 300mm Glass wool insulation | | 16,154 | 16,154 | 16,376 | 16,562 | 16,719 | 16,851 | 16,962 | 17,056 | 17,135 | 17,201 | 17,257 |
| Temp Ocean Discount % | year 5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 190mm Polyurethane insulation | | 12,865 | 12,865 | 13,068 | 13,227 | 13,351 | 13,449 | 13,525 | 13,585 | 13,632 | 13,669 | 13,698 |
| 310mm Stone wool insulation | | 16,324 | 16,324 | 16,527 | 16,686 | 16,811 | 16,908 | 16,985 | 17,045 | 17,092 | 17,129 | 17,157 |
| 300mm Glass wool insulation | | 16,154 | 16,154 | 16,357 | 16,516 | 16,641 | 16,739 | 16,815 | 16,875 | 16,922 | 16,959 | 16,988 |

**Table12** LCC pitched new roof: Temperate Oceanic

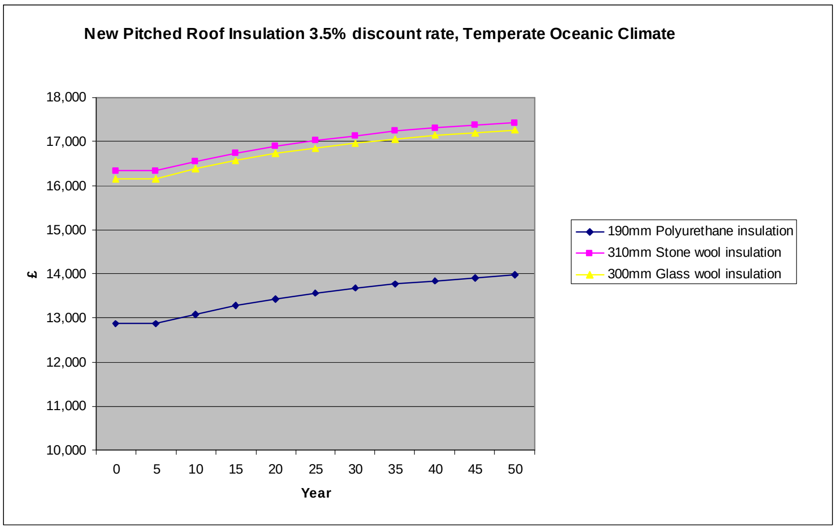



**Figure 26** LCC new pitched roof: Temperate Oceanic.

## Conclusion

190mm polyurethane has the lowest life cycle cost in the Temperate Oceanic climate zone, followed by 300mm glass wool insulation and 310mm stone wool.

**Part 1 New Pitched Roof Slopes: Temperate Mediterranean**

| Temp. Med. Discount % | year 0% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 190mm Polyurethane insulation | | 12,865 | 12,865 | 13,137 | 13,409 | 13,681 | 13,953 | 14,224 | 14,496 | 14,768 | 15,040 | 15,312 |
| 310mm Stone wool insulation | | 16,324 | 16,324 | 16,596 | 16,868 | 17,140 | 17,412 | 17,684 | 17,956 | 18,228 | 18,500 | 18,772 |
| 300mm Glass wool insulation | | 16,154 | 16,154 | 16,426 | 16,698 | 16,970 | 17,242 | 17,514 | 17,786 | 18,058 | 18,330 | 18,602 |

| Temp. Med. Discount % | year 3.5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 190mm Polyurethane insulation | | 12,865 | 12,865 | 13,086 | 13,272 | 13,429 | 13,561 | 13,672 | 13,766 | 13,845 | 13,911 | 13,967 |
| 310mm Stone wool insulation | | 16,324 | 16,324 | 16,546 | 16,732 | 16,889 | 17,021 | 17,132 | 17,226 | 17,304 | 17,371 | 17,427 |
| 300mm Glass wool insulation | | 16,154 | 16,154 | 16,376 | 16,562 | 16,719 | 16,851 | 16,962 | 17,056 | 17,135 | 17,201 | 17,257 |

| Temp. Med. Discount % | year 5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 190mm Polyurethane insulation | | 12,865 | 12,865 | 13,068 | 13,227 | 13,351 | 13,449 | 13,525 | 13,585 | 13,632 | 13,669 | 13,698 |
| 310mm Stone wool insulation | | 16,324 | 16,324 | 16,527 | 16,686 | 16,811 | 16,908 | 16,985 | 17,045 | 17,092 | 17,129 | 17,157 |
| 300mm Glass wool insulation | | 16,154 | 16,154 | 16,357 | 16,516 | 16,641 | 16,739 | 16,815 | 16,875 | 16,922 | 16,959 | 16,988 |

**Table 13** LCC new pitched roof: Temperate Mediterranean

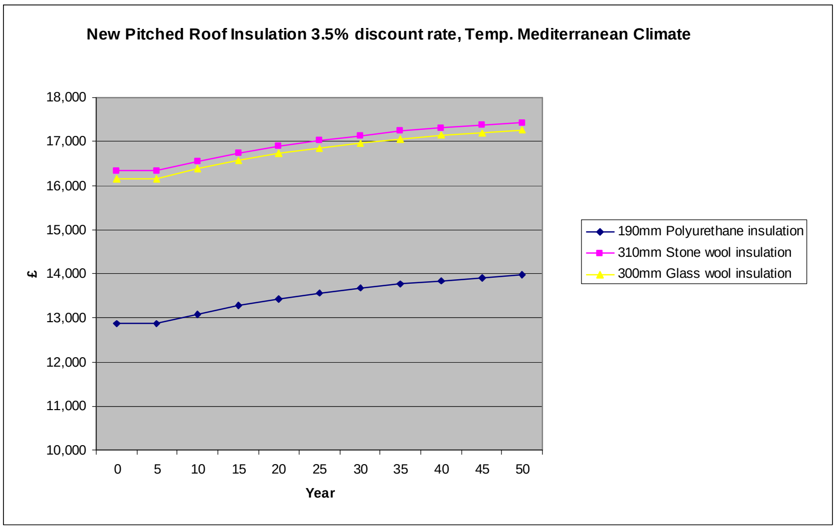



**Figure 27** LCC new pitched roof: Temperate Mediterranean.

## Conclusion

190mm polyurethane has the lowest life cycle cost in the Temperate Mediterranean climate zone, followed by 300mm glass wool insulation and 310mm stone wool.

| Part 1 New Pitched Roof Slopes: Cool Continental | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cool Cont. Discount %** year 0% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 190mm Polyurethane insulation | 12,865 | 12,865 | 13,137 | 13,409 | 13,681 | 13,953 | 14,224 | 14,496 | 14,768 | 15,040 | 15,312 |
| 310mm Stone wool insulation | 16,332 | 16,332 | 16,604 | 16,876 | 17,148 | 17,420 | 17,692 | 17,964 | 18,236 | 18,508 | 18,779 |
| 300mm Glass wool insulation | 16,154 | 16,154 | 16,426 | 16,698 | 16,970 | 17,242 | 17,514 | 17,786 | 18,058 | 18,330 | 18,602 |
| **Cool Cont. Discount %** year 3.5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 190mm Polyurethane insulation | 12,865 | 12,865 | 13,086 | 13,272 | 13,429 | 13,561 | 13,672 | 13,766 | 13,845 | 13,911 | 13,967 |
| 310mm Stone wool insulation | 16,332 | 16,332 | 16,553 | 16,739 | 16,896 | 17,028 | 17,139 | 17,233 | 17,312 | 17,378 | 17,434 |
| 300mm Glass wool insulation | 16,154 | 16,154 | 16,376 | 16,562 | 16,719 | 16,851 | 16,962 | 17,056 | 17,135 | 17,201 | 17,257 |
| **Cool Cont. Discount %** year 5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 190mm Polyurethane insulation | 12,865 | 12,865 | 13,068 | 13,227 | 13,351 | 13,449 | 13,525 | 13,585 | 13,632 | 13,669 | 13,698 |
| 310mm Stone wool insulation | 16,332 | 16,332 | 16,535 | 16,694 | 16,818 | 16,916 | 16,992 | 17,052 | 17,099 | 17,136 | 17,165 |
| 300mm Glass wool insulation | 16,154 | 16,154 | 16,357 | 16,516 | 16,641 | 16,739 | 16,815 | 16,875 | 16,922 | 16,959 | 16,988 |

**Table 14** LCC new pitched roof: Cool Continental

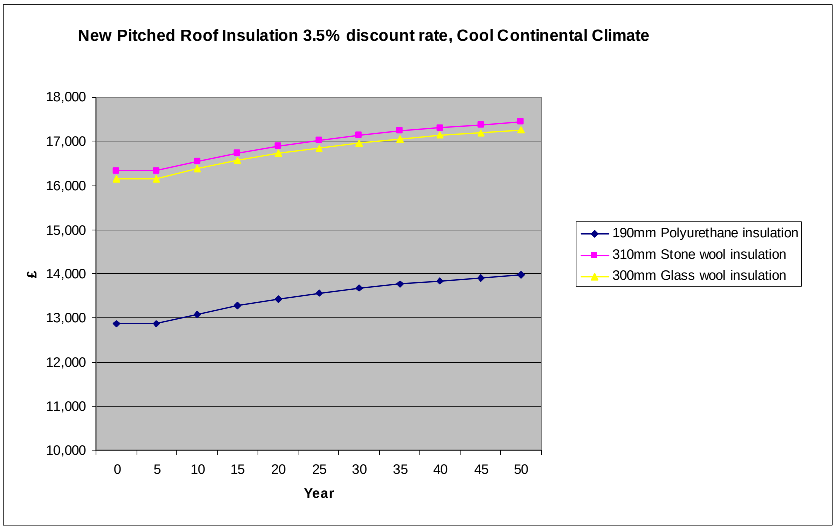



**Figure 28** LCC new pitched roof: Cool Continental.

## Conclusion

190mm polyurethane has the lowest life cycle cost in the Cool Continental climate zone, followed by 300mm glass wool insulation and 310mm stone wool.

## LCC New ground floor

The new floor construction includes 200mm thick reinforced concrete ground slab and 50mm reinforced screed. Insulation materials and thicknesses vary as required. Standard external walls with 50mm cavity have been assumed for all insulation types.

Insulation materials for the different scenarios included in this section are as follows:

95mm thick polyurethane; density 32kg/m$^3$; k-value of 0.023

185mm thick expanded polystyrene; density 18.5kg/m$^3$; k-value of 0.030

Because no maintenance or replacement is anticipated during the study period, no life cycle costs are included. The determining cost is the initial installation cost.

| Part 1 New Ground Floor: Temperate Oceanic | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp Ocean Discount % | year 0% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 95mm Polyurethane insulation | | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 |
| 185mm Expanded Polystyrene insulati | | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 |
| Temp Ocean Discount % | year 3.5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 95mm Polyurethane insulation | | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 |
| 185mm Expanded Polystyrene insulati | | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 |
| Temp Ocean Discount % | year 5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 95mm Polyurethane insulation | | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 |
| 185mm Expanded Polystyrene insulati | | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 |

**Table 15** LCC new ground floor: Temperate Oceanic

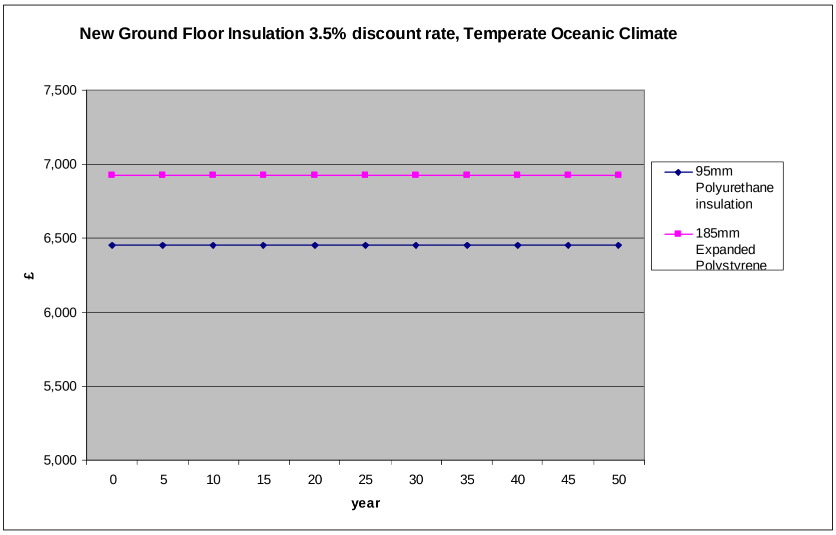



**Figure 29** LCC new ground floor: Temperate Oceanic.

## Conclusion

95mm polyurethane insulation has the lower life cycle cost in the Temperate Oceanic climate zone, followed by 185mm expanded polystyrene.

**Part 1 New Ground Floor: Temperate Mediterranean**

| Temp. Med. Discount % | year 0% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95mm Polyurethane insulation | | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 |
| 185mm Expanded Polystyrene insula | | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 |

| Temp. Med. Discount % | year 3.5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95mm Polyurethane insulation | | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 |
| 185mm Expanded Polystyrene insula | | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 |

| Temp. Med. Discount % | year 5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95mm Polyurethane insulation | | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 |
| 185mm Expanded Polystyrene insula | | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 |

**Table 16** LCC new ground floor: Temperate Mediterranean

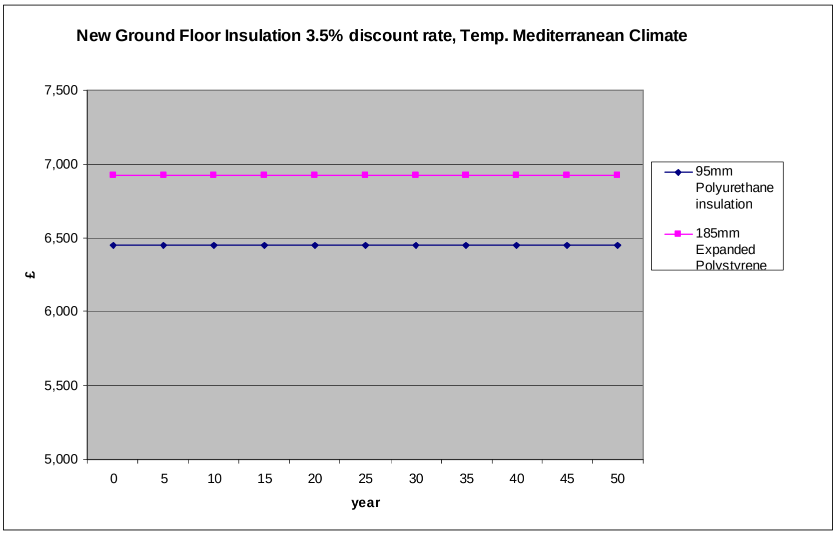



**Figure 30** LCC new ground floor: Temperate Mediterranean.

## Conclusion

95mm polyurethane insulation has the lower life cycle cost in the Temperate Mediterranean climate zone, followed by 185mm expanded polystyrene

| Part 1 New Ground Floor: Cool Continental | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cool Cont. Discount %** year 0% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 95mm Polyurethane insulation | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 |
| 185mm Expanded Polystyrene insu | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 |
| **Cool Cont. Discount %** year 3.5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 95mm Polyurethane insulation | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 |
| 185mm Expanded Polystyrene insu | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 |
| **Cool Cont. Discount %** year 5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 95mm Polyurethane insulation | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 | 6,448 |
| 185mm Expanded Polystyrene insu | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 | 6,921 |

**Table 17** LCC new ground floor: Cool Continental

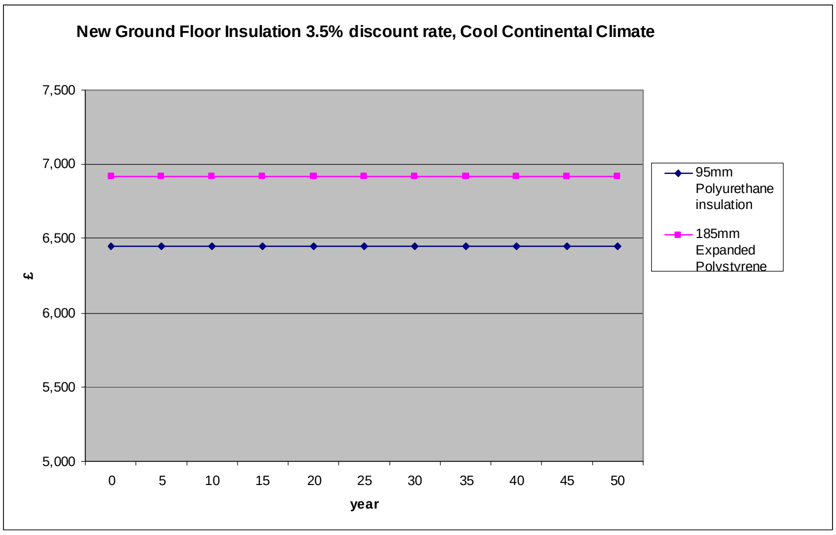



**Figure 31** LCC new ground floor: Cool Continental.

## Conclusion

95mm polyurethane insulation has the lower life cycle cost in the Cool Continental climate zone, followed by 185mm expanded polystyrene.

### 3.2.1 Affect on building footprint

The new cavity wall – different thicknesses of wall insulation lead to different quantities of materials for the wall and hence higher construction costs. An additional cost/$m^2$ for this is included with the new wall calculations.

The pitched roof assumes a standard size of external wall for all insulation options.

The ground floor assumes a standard size of external wall for all insulation options.

One effect of the new cavity wall not shown in the tables is the additional footprint area required for roof and floor. On a large building site this may affect the density or number of properties that could be built on the site, e.g. in the worst case, 8.00$m^2$ extra on the roof area for each property may mean that only 9 properties could be fitted in an area that may be able to accommodate 10 if the external walls were thinner and the roof not extending over such a large area.

Coupled with this, but not included in the calculations is the possible value of the land that is unable to be utilised. Although prices vary considerably, a realistic cost of land with planning permission in an urban area in the United Kingdom, for example, is £250/m2. Related to the 8.00m2 area noted above, this would equate to £2,000 capital outlay on which there would be no return in the form of property.

In Part 1 New roof, the gross internal ground floor area is 52$m^2$, but the external plan area of the pitched roof is 75$m^2$ which includes for roof over the external walls with 450mm soffit overhang.

## 3.3 Part 2 Refurbishment: external walls LCC

**LCC refurbished wall**

In Part 2, an existing building is assumed with uninsulated external walls. The project requires insulation to be added, but in order to maintain internal floor areas; a restriction is imposed to allow insulation to a maximum of 50mm thick plus plasterboard finish. Materials modelled are polyurethane, stone wool, glass wool or expanded polystyrene.

Insulation is required to be added to the internal face of an existing property and it is assumed that the wall comprises half brick thick outer skin of facing bricks, 50mm thick cavity, inner skin of 100mm thick dense blocks, 12.5mm plasterboard with 2 coats of emulsion paint. 50m thick insulation is either fixed directly to the blockwork with adhesive or between softwood framework as appropriate.

Energy costs are included in this section.

Insulation materials for the different scenarios included in this section are as follows:

50mm thick polyurethane fixed to block wall with adhesive; density 32kg/m$^3$; k-value of 0.023

50mm thick stone wool fixed between timber studs; density 39kg/m$^3$; k-value of 0.037

50mm thick glass wool fixed between timber studs; density 24kg/m$^3$; k-value of 0.035

50mm thick expanded polystyrene fixed to block wall with adhesive; density 30kg/m$^3$; k-value of 0.034

The following life cycle costs have been included - internal redecorations (5 years), rainwater goods, renew fascias and repoint brickwork (30 years) and annual energy consumed in each location. (For energy calculations, see Appendix A)

**Part 2 Internal Lining to Existing Wall: Temperate Oceanic**

| **Temp Ocean Discount %** | year 0% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50mm Polyurethane insulation | | 4,070 | 6,141 | 8,876 | 11,610 | 14,345 | 17,079 | 23,004 | 25,739 | 28,473 | 31,208 | 33,943 |
| 50mm Stone wool insulation | | 5,276 | 7,547 | 10,483 | 13,418 | 16,353 | 19,288 | 25,413 | 28,348 | 31,283 | 34,218 | 37,154 |
| 50mm Glass wool insulation | | 5,264 | 7,535 | 10,470 | 13,406 | 16,341 | 19,276 | 24,947 | 27,882 | 30,817 | 33,752 | 36,687 |
| 50mm Expanded Polystyrene insulatio | | 4,454 | 6,648 | 9,506 | 12,363 | 15,220 | 18,078 | 24,125 | 26,543 | 29,401 | 32,258 | 35,116 |
| **Temp Ocean Discount %** | year 3.5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 50mm Polyurethane insulation | | 4,070 | 5,940 | 8,054 | 9,835 | 11,334 | 12,596 | 14,795 | 15,690 | 16,443 | 17,077 | 17,611 |
| 50mm Stone wool insulation | | 5,276 | 7,327 | 9,594 | 11,503 | 13,110 | 14,463 | 16,739 | 17,698 | 18,505 | 19,185 | 19,758 |
| 50mm Glass wool insulation | | 5,264 | 7,315 | 9,582 | 11,491 | 13,098 | 14,451 | 16,565 | 17,524 | 18,331 | 19,011 | 19,584 |
| 50mm Expanded Polystyrene insulatio | | 4,454 | 6,435 | 8,643 | 10,502 | 12,067 | 13,385 | 15,631 | 16,434 | 17,220 | 17,882 | 18,440 |
| **Temp Ocean Discount %** | year 5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 50mm Polyurethane insulation | | 4,070 | 5,863 | 7,763 | 9,252 | 10,419 | 11,333 | 12,787 | 13,348 | 13,788 | 14,133 | 14,402 |
| 50mm Stone wool insulation | | 5,276 | 7,243 | 9,279 | 10,875 | 12,125 | 13,104 | 14,610 | 15,211 | 15,682 | 16,051 | 16,341 |
| 50mm Glass wool insulation | | 5,264 | 7,231 | 9,267 | 10,862 | 12,113 | 13,092 | 14,492 | 15,094 | 15,565 | 15,934 | 16,223 |
| 50mm Expanded Polystyrene insulatio | | 4,454 | 6,354 | 8,337 | 9,892 | 11,109 | 12,063 | 13,549 | 14,055 | 14,514 | 14,874 | 15,156 |

**Table 18** LCC existing wall: Temperate Oceanic

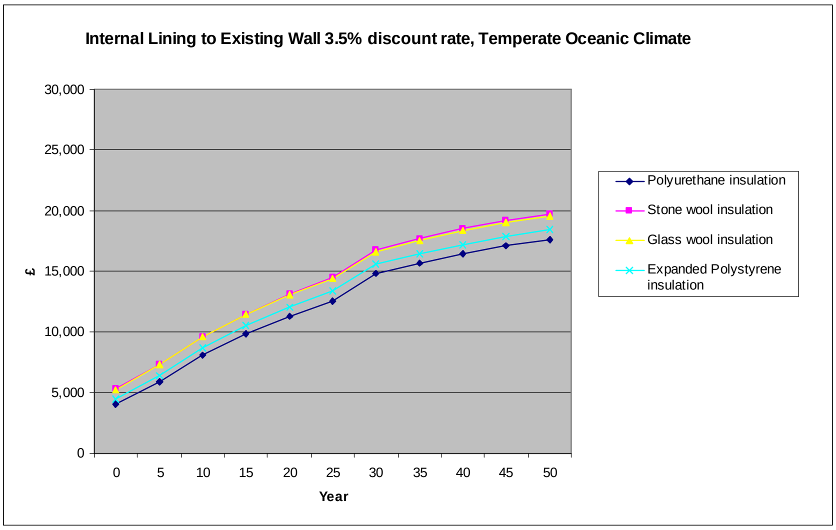



**Figure 32** LCC existing wall: Temperate Oceanic.

## Conclusion

Polyurethane insulation has the lowest life cycle cost, followed by expanded polystyrene, glass wool and stone wool in the Temperate Oceanic climate zone.

| Part 2 Internal Lining to Existing Wall: Temperate Mediterranean | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Temp. Med. Discount %** | year 0% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 50mm Polyurethane insulation | | 4,070 | 5,852 | 8,298 | 10,744 | 13,190 | 15,636 | 21,272 | 23,718 | 26,164 | 28,610 | 31,056 |
| 50mm Stone wool insulation | | 5,276 | 7,225 | 9,837 | 12,450 | 15,063 | 17,675 | 23,478 | 26,090 | 28,703 | 31,316 | 33,928 |
| 50mm Glass wool insulation | | 5,264 | 7,213 | 9,825 | 12,438 | 15,051 | 17,663 | 23,076 | 25,689 | 28,301 | 30,914 | 33,526 |
| 50mm Expanded Polystyrene insulat | | 4,454 | 6,339 | 8,887 | 11,435 | 13,983 | 16,531 | 22,269 | 24,440 | 26,988 | 29,535 | 32,083 |
| **Temp. Med. Discount %** | year 3.5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 50mm Polyurethane insulation | | 4,070 | 5,679 | 7,574 | 9,170 | 10,513 | 11,644 | 13,733 | 14,535 | 15,210 | 15,779 | 16,257 |
| 50mm Stone wool insulation | | 5,276 | 7,036 | 9,057 | 10,760 | 12,193 | 13,400 | 15,552 | 16,408 | 17,128 | 17,734 | 18,245 |
| 50mm Glass wool insulation | | 5,264 | 7,024 | 9,045 | 10,748 | 12,181 | 13,388 | 15,401 | 16,257 | 16,977 | 17,583 | 18,094 |
| 50mm Expanded Polystyrene insulat | | 4,454 | 6,156 | 8,129 | 9,789 | 11,188 | 12,365 | 14,493 | 15,214 | 15,917 | 16,509 | 17,007 |
| **Temp. Med. Discount %** | year 5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 50mm Polyurethane insulation | | 4,070 | 5,613 | 7,318 | 8,653 | 9,699 | 10,519 | 11,900 | 12,403 | 12,797 | 13,106 | 13,349 |
| 50mm Stone wool insulation | | 5,276 | 6,963 | 8,781 | 10,205 | 11,321 | 12,195 | 13,618 | 14,155 | 14,575 | 14,905 | 15,163 |
| 50mm Glass wool insulation | | 5,264 | 6,951 | 8,769 | 10,193 | 11,309 | 12,183 | 13,516 | 14,052 | 14,473 | 14,802 | 15,061 |
| 50mm Expanded Polystyrene insulat | | 4,454 | 6,086 | 7,860 | 9,249 | 10,338 | 11,191 | 12,598 | 13,053 | 13,464 | 13,785 | 14,037 |

**Table 19** LCC existing wall: Temperate Mediterranean

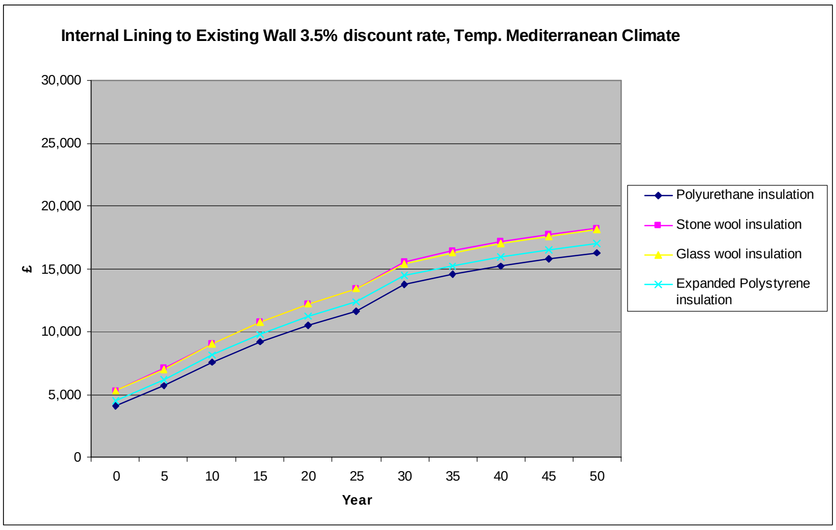



**Figure 33** LCC existing wall: Temperate Mediterranean.

## Conclusion

Polyurethane insulation has the lowest life cycle cost, followed by expanded polystyrene, glass wool and stone wool, when used in Temperate Mediterranean

| Part 2 Internal Lining to Existing Wall: Cool Continental | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cool Cont. Discount %** year 0% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 50mm Polyurethane insulation | 4,070 | 7,881 | 12,355 | 16,830 | 21,304 | 25,779 | 33,443 | 37,918 | 42,393 | 46,867 | 51,342 |
| 50mm Stone wool insulation | 5,276 | 9,448 | 14,284 | 19,120 | 23,955 | 28,791 | 36,817 | 41,653 | 46,489 | 51,324 | 56,160 |
| 50mm Glass wool insulation | 5,264 | 9,436 | 14,272 | 19,108 | 23,943 | 28,779 | 35,970 | 40,806 | 45,642 | 50,478 | 55,314 |
| 50mm Expanded Polystyrene insul | 4,454 | 8,487 | 13,182 | 17,878 | 22,574 | 27,270 | 35,156 | 39,045 | 43,741 | 48,436 | 53,132 |
| **Cool Cont. Discount %** year 3.5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 50mm Polyurethane insulation | 4,070 | 7,511 | 10,948 | 13,843 | 16,279 | 18,331 | 21,195 | 22,650 | 23,874 | 24,905 | 25,774 |
| 50mm Stone wool insulation | 5,276 | 9,043 | 12,755 | 15,881 | 18,512 | 20,728 | 23,730 | 25,301 | 26,623 | 27,737 | 28,674 |
| 50mm Glass wool insulation | 5,264 | 9,031 | 12,743 | 15,869 | 18,500 | 20,716 | 23,421 | 24,991 | 26,314 | 27,427 | 28,365 |
| 50mm Expanded Polystyrene insul | 4,454 | 8,096 | 11,701 | 14,737 | 17,293 | 19,445 | 22,394 | 23,677 | 24,962 | 26,043 | 26,954 |
| **Cool Cont. Discount %** year 5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 50mm Polyurethane insulation | 4,070 | 7,370 | 10,450 | 12,864 | 14,756 | 16,237 | 18,137 | 19,046 | 19,759 | 20,318 | 20,755 |
| 50mm Stone wool insulation | 5,276 | 8,889 | 12,214 | 14,820 | 16,862 | 18,462 | 20,453 | 21,435 | 22,205 | 22,808 | 23,280 |
| 50mm Glass wool insulation | 5,264 | 8,876 | 12,202 | 14,808 | 16,850 | 18,450 | 20,248 | 21,230 | 22,000 | 22,603 | 23,075 |
| 50mm Expanded Polystyrene insul | 4,454 | 7,946 | 11,177 | 13,708 | 15,692 | 17,246 | 19,201 | 20,009 | 20,757 | 21,342 | 21,801 |

**Table 20** LCC existing wall Cool Continental

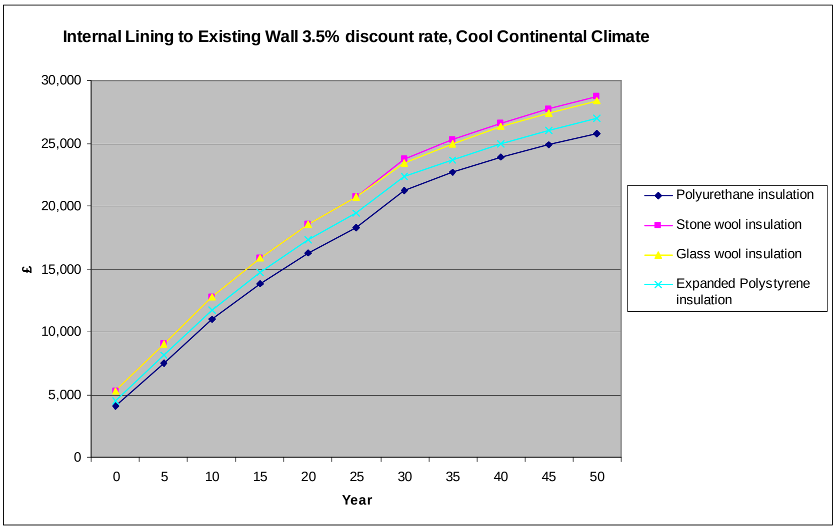



**Figure 34** LCC existing wall Cool Continental.

## Conclusion

Polyurethane insulation has the lowest life cycle cost, followed by expanded polystyrene, glass wool and stone wool in the Cool Continental climate zone.

### 3.4 Part 3 New warm deck flat roof LCC

**LCC Flat roofing**

In Part 3, a flat roof is considered and models the effect of polyurethane, stone wool and expanded polystyrene. The flat roof structure comprises 100mm x 50mm softwood joists, plates and strutting, 19mm OSB tongue and grooved boarding, vapour barrier and single ply membrane, plasterboard ceiling with 2 coats of emulsion paint. Insulation materials and thicknesses vary as required.

Energy costs are included in this section.

Insulation materials for the different scenarios included in this section are as follows:

150mm thick polyurethane; density 32kg/m$^3$; k-value of 0.023

255mm thick stone wool; density 130kg/m$^3$; k-value of 0.038

255mm thick expanded polystyrene; density 30kg/$^{m3}$; k-value of 0.034

Life cycle costs allow for renewing the roof covering (25 years), redecorating the ceiling (5 years) and annual energy consumed in each location. (For energy calculations, see Appendix A).

**Part 3 Flat Roof Insulation: Temperate Oceanic**

| **Temp Ocean Discount %** | year 0% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 150mm Polyurethane insulation | | 9,999 | 11,273 | 12,819 | 14,365 | 15,911 | 17,457 | 21,051 | 22,598 | 24,144 | 25,690 | 27,236 |
| 255mm Stone wool insulation | | 10,897 | 12,171 | 13,718 | 15,264 | 16,810 | 18,356 | 21,950 | 23,496 | 25,042 | 26,588 | 28,134 |
| 255mm Expanded Polystyrene insula | | 10,941 | 12,216 | 13,762 | 15,308 | 16,854 | 18,400 | 21,739 | 23,285 | 24,832 | 26,378 | 27,924 |

| **Temp Ocean Discount %** | year 3.5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 150mm Polyurethane insulation | | 9,999 | 11,149 | 12,339 | 13,341 | 14,185 | 14,895 | 16,330 | 16,834 | 17,258 | 17,615 | 17,916 |
| 255mm Stone wool insulation | | 10,897 | 12,048 | 13,238 | 14,240 | 15,083 | 15,794 | 17,229 | 17,733 | 18,157 | 18,514 | 18,814 |
| 255mm Expanded Polystyrene insula | | 10,941 | 12,092 | 13,282 | 14,284 | 15,128 | 15,838 | 17,182 | 17,686 | 18,110 | 18,467 | 18,767 |

| **Temp Ocean Discount %** | year 5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 150mm Polyurethane insulation | | 9,999 | 11,102 | 12,169 | 13,006 | 13,661 | 14,174 | 15,153 | 15,468 | 15,715 | 15,908 | 16,060 |
| 255mm Stone wool insulation | | 10,897 | 12,001 | 13,068 | 13,904 | 14,560 | 15,073 | 16,051 | 16,366 | 16,613 | 16,807 | 16,959 |
| 255mm Expanded Polystyrene insula | | 10,941 | 12,045 | 13,112 | 13,948 | 14,604 | 15,117 | 16,036 | 16,352 | 16,599 | 16,792 | 16,944 |

**Table 21** LCC Flat roof: Temperate Oceanic

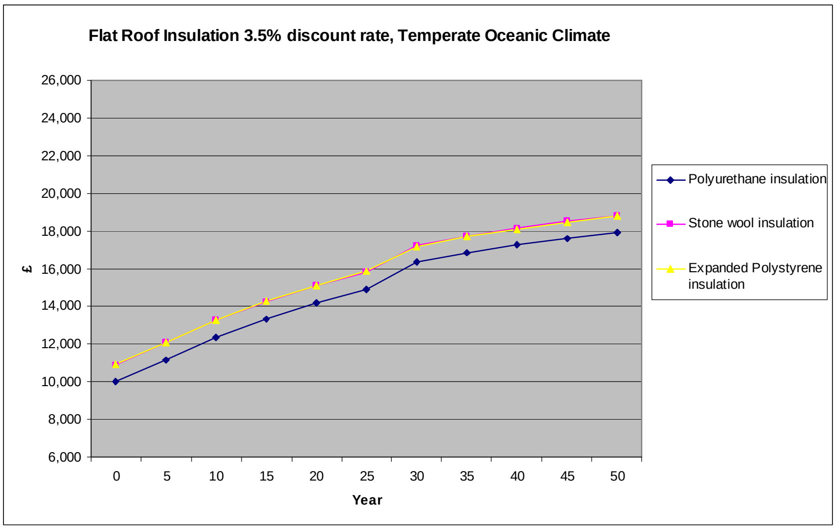



**Figure 35** LCC Flat roof: Temperate Oceanic.

## Conclusion

150mm polyurethane has the lowest life cycle cost in the Temperate Oceanic climate zone, followed by 255mm expanded polystyrene and 255mm stone wool insulation.

**Part 3 Flat Roof Insulation: Temperate Mediterranean**

| Temp. Med. Discount % | year 0% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 150mm Polyurethane insulation | | 9,999 | 11,132 | 12,537 | 13,942 | 15,347 | 16,752 | 20,205 | 21,610 | 23,015 | 24,420 | 25,825 |
| 255mm Stone wool insulation | | 10,897 | 12,030 | 13,435 | 14,841 | 16,246 | 17,651 | 21,104 | 22,509 | 23,914 | 25,319 | 26,724 |
| 255mm Expanded Polystyrene insula | | 10,941 | 12,075 | 13,480 | 14,885 | 16,290 | 17,695 | 20,921 | 22,326 | 23,731 | 25,136 | 26,541 |

| Temp. Med. Discount % | year 3.5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 150mm Polyurethane insulation | | 9,999 | 11,022 | 12,105 | 13,016 | 13,784 | 14,430 | 15,812 | 16,270 | 16,656 | 16,980 | 17,254 |
| 255mm Stone wool insulation | | 10,897 | 11,921 | 13,003 | 13,915 | 14,682 | 15,329 | 16,710 | 17,168 | 17,554 | 17,879 | 18,152 |
| 255mm Expanded Polystyrene insula | | 10,941 | 11,965 | 13,047 | 13,959 | 14,727 | 15,373 | 16,674 | 17,132 | 17,518 | 17,842 | 18,116 |

| Temp. Med. Discount % | year 5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 150mm Polyurethane insulation | | 9,999 | 10,980 | 11,952 | 12,713 | 13,309 | 13,777 | 14,719 | 15,006 | 15,231 | 15,407 | 15,545 |
| 255mm Stone wool insulation | | 10,897 | 11,878 | 12,850 | 13,611 | 14,208 | 14,675 | 15,618 | 15,905 | 16,129 | 16,306 | 16,444 |
| 255mm Expanded Polystyrene insula | | 10,941 | 11,923 | 12,894 | 13,656 | 14,252 | 14,720 | 15,609 | 15,896 | 16,121 | 16,297 | 16,435 |

**Table 22** LCC Flat roof: Temperate Mediterranean

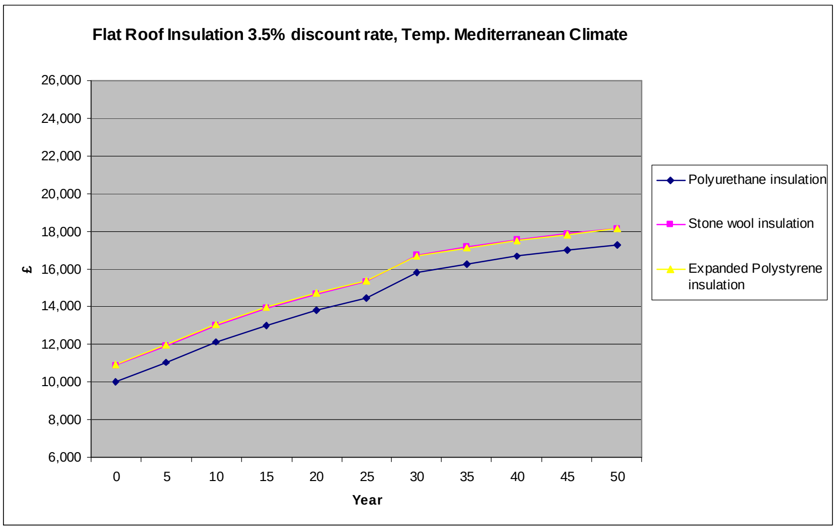



**Figure 36** LCC Flat roof: Temperate Mediterranean.

## Conclusion

150mm polyurethane has the lowest life cycle cost in the Temperate Mediterranean climate zone, followed by 255mm expanded polystyrene and 255mm stone wool insulation.

**Part 3 Flat Roof Insulation: Cool Continental**

| Cool Cont. Discount % | year 0% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 150mm Polyurethane insulation | | 9,999 | 12,344 | 14,961 | 17,578 | 20,194 | 22,811 | 27,476 | 30,093 | 32,710 | 35,327 | 37,944 |
| 255mm Stone wool insulation | | 10,897 | 13,242 | 15,859 | 18,476 | 21,093 | 23,710 | 28,375 | 30,992 | 33,609 | 36,226 | 38,842 |
| 255mm Expanded Polystyrene insu | | 10,941 | 13,286 | 15,903 | 18,520 | 21,137 | 23,754 | 27,950 | 30,567 | 33,184 | 35,801 | 38,418 |

| Cool Cont. Discount % | year 3.5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 150mm Polyurethane insulation | | 9,999 | 12,116 | 14,120 | 15,808 | 17,229 | 18,425 | 20,269 | 21,117 | 21,831 | 22,433 | 22,939 |
| 255mm Stone wool insulation | | 10,897 | 13,015 | 15,019 | 16,706 | 18,127 | 19,323 | 21,168 | 22,016 | 22,730 | 23,331 | 23,837 |
| 255mm Expanded Polystyrene insu | | 10,941 | 13,059 | 15,063 | 16,751 | 18,171 | 19,368 | 21,045 | 21,893 | 22,607 | 23,208 | 23,714 |

| Cool Cont. Discount % | year 5% | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 150mm Polyurethane insulation | | 9,999 | 12,029 | 13,823 | 15,229 | 16,330 | 17,193 | 18,445 | 18,975 | 19,390 | 19,715 | 19,970 |
| 255mm Stone wool insulation | | 10,897 | 12,928 | 14,722 | 16,127 | 17,229 | 18,091 | 19,343 | 19,873 | 20,288 | 20,613 | 20,868 |
| 255mm Expanded Polystyrene insu | | 10,941 | 12,972 | 14,766 | 16,171 | 17,273 | 18,136 | 19,279 | 19,809 | 20,224 | 20,549 | 20,804 |

**Table 23** LCC Flat roof: Cool Continental

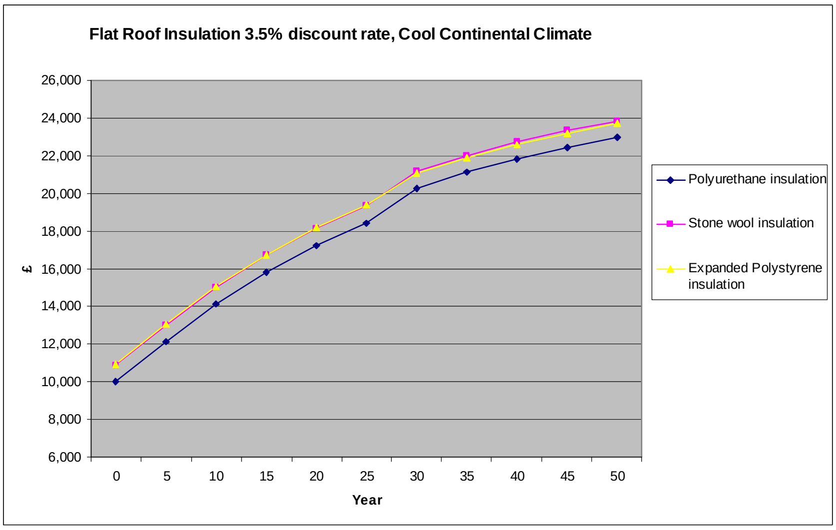



**Figure 37** LCC Flat roof: Cool Continental.

## Conclusion

150mm polyurethane has the lowest life cycle cost in the Cool Continental climate zone, followed by 255mm expanded polystyrene and 255mm stone wool insulation.

### 3.4.1 Flat roof loading.

Calculations have been carried out by a structural engineer, that show that the impact of the different weights of insulation materials, owing to the different thicknesses required, have a negligible effect on the overall mass of the building and would be unlikely to incur any additional cost to the structure. If stone wool, the heaviest of the insulating materials at 130kg/m$^3$, were to require an increase in joist size from 100mm to 150mm deep, this would cost approximately £115 extra for the whole flat roof. This would have no effect on the overall results of the life cycle costing exercise.

# 4 Conclusion

## 4.1 Environmental impacts

The following conclusions, based mainly on the normalised results, have been drawn from the LCA studies:

1) The results from Part 1 indicated that the PU designs tended to have similar or higher environmental impacts than those for the designs using alternative insulation materials at the same level of thermal performance. Part 3's results indicated that when insulations need mechanical properties in addition to their thermal performance, then solutions using PU can have environmental impacts similar to or lower than alternative insulations.

2) Part 1 further indicates that the materials of the modelled house accounted for around one third of the total Global Warming, and 50 to 90% of the whole house impact in Ozone Depletion, Eutrophication, Photochemical Ozone Creation and Acidification for Air and Water over 50 years for all climate zones.

3) The results from Part 2 show that where the amount of insulation is fixed, rather than the U-value, then the greater energy savings achieved with using PU insulation offset the higher environmental impact of the PU insulation itself.

4) The results from Part 2 imply that:

    a. if the cavity is kept at the thickness needed for stone wool and glass wool in Part 1 to achieve the set U-value of 0.15 W $m^{-2}K^{-1}$ then the extra PU insulation that could be incorporated would save energy in use, which could more than offset the extra impact of the PU material and may offer greater benefits as demonstrated in Part 2.

    b. if stone wool and glass wool were modelled at the same cavity thickness as for the PU model in this project, it is likely that stone wool and glass wool would require more energy during use, which could offset the lower environmental impacts of these insulations.

These conclusions on the relative performance of materials and energy use are influenced by the assumption that the space heating accounts for the majority of the energy consumption of using the house.

BRE Global recommends that the assessments outlined in a) and b) above are carried out with models for the specifications and energy models that are relevant to the climate zones of interest.

Additionally, the energy models have assumed a common airtightness and junction y value for all models. The relevance of this assumption to the results is another further area of research.

## 4.2 Cost impacts

The following conclusions have been drawn from the LCC studies.

1. The results for Part 1 cavity wall infill indicates that for all regions considered, 180mm polyurethane insulation used in the cavity has the lowest life cycle cost, followed by 270mm glass wool and 270mm stone wool.

2. Greater thicknesses of wall insulation required increased quantities of materials for the wall and hence higher construction costs. An additional cost/$m^2$ for this is included with the new wall calculations. One effect of a thicker new cavity wall is the additional footprint area required for roof and floor. On a large building site this may affect the density or number of properties that could be built on the site, e.g. in the worst case, 8.00$m^2$ extra on the roof area for each property may mean that only 9 properties could be fitted in an area that may be able to accommodate 10 if the external walls were thinner and the roof smaller.

3. The results for a new pitched roof with insulation between and over the rafters to achieve a common U value indicate that 190mm polyurethane has the lowest life cycle cost when used in all regions followed by 300mm glass wool insulation and 310mm stone wool.

4. The results for the new ground floor indicates that 95mm polyurethane insulation has the lower life cycle cost when used in all regions, followed by 185mm expanded polystyrene.

5. The results for Part 2 refurbishment of an existing wall by the addition of 50mm insulation to the inside face indicates that polyurethane insulation has the lowest life cycle cost, followed by expanded polystyrene, glass wool and stone wool in all regions.

6. The results for Part 3 new warm deck flat roof indicates that 150mm polyurethane has the lowest life cycle cost when used in all regions, followed by 255mm expanded polystyrene and 255mm stone wool insulation.

# Appendix 1

## Thermal assessment and energy calculations

### Introduction

The overall objective of the BING Project study is to quantify the PU insulation contribution on the environmental and economic performance in low-energy buildings and compare it to the use of alternative insulation materials relevant to the considered applications.

The study is in 3 parts:-

Part 1: impact of insulation in new build for total building perspective;

Part 2: impact of insulation in renovation when thickness is restricted;

Part 3: impact of insulation density with new build flat roof

For each of the three parts a specific house type and size is used, where this was selected as the small detached house from BRE Client Report "Standard Dwellings for Energy Modelling" (CR444/98) by Peter Iles. The total floor area of the two storey house is 104 m² with the heating system, lighting etc. fixed, with only the insulation of the building fabric varying.

### U-values and Insulation thicknesses

Part 1. New build – impact of thermal conductivity

For Part 1 where the different insulation materials are used in new build constructions, the building element constructions of wall, roof and floor have insulation thicknesses such that the same U-value is achieved for the different insulation materials. The window U-value is fixed at 2.1 W/m²K and the heat loss associated with the thermal bridging at the junctions between building elements and around openings has a y-value of 0.08 W/m²K.

Part 2. Existing build - Impact of thickness restriction

For Part 2, insulation of the walls of the dwelling is restricted to adding 50mm thickness of insulation to the inside of an uninsulated brick/cavity/block wall. This results in different U-values for the different insulation materials used in the wall. The roof is taken to be insulated between joists with 100 mm of insulation and the floor construction is taken to be uninsulated resulting in fixed U-values of 0.40 and 0.67 W/m²K for the roof and ground floor, respectively. The U-value of the windows is fixed at 2.7 W/m²K and the heat loss associated with the thermal bridging at the junctions between building elements and around openings considered to have a y-value of 0.15 W/m²K.

Part 3. New build – Flat roof

For Part 3, the roof of the dwelling is replaced with a flat roof with a U-value of 0.15 W/m²K. As for Part 1 the window U-value is fixed at 2.1 W/m²K and the heat loss associated with the thermal bridging at the junctions between building elements and around openings again has a y-value of 0.08 W/m²K.

**Calculation of Energy emissions for space heating**

The energy used for space heating is calculated using a version BRESAP amended for different external climates. The three climatic regions covered are Temperate Oceanic, Temperate Mediterranean and Cool Continental, where the external climate data for each being sourced from the Photovoltaic Geographical Information System (PVGIS) where the data used is the 24 hour mean monthly values of external temperature and solar radiation.

There is of course a clear difference in energy consumptions for space heating between each of the three different external climates. Using the Temperate Oceanic zone as the base consumption (bold text values), for Temperate Mediterranean the consumptions are 18% less for all builds. For Cool Continental and for the new builds (Parts 1 and 3), the consumptions are 140% higher compared to the TO zone and for the existing builds (Part2) the consumptions are about 110% more in the CC zone compared to that for the TO.

For the existing build (Part2) and for all three external climates, using the PU internal insulation as the base case (Red text values), the space heating consumption with the EPS insulation on the wall is 8% more and that for the SW/GW insulation on the wall is around 11% more.

| | U-values (W/m²K) | | | | Junctions y-value | Temperate Mediterranean (TM) | Temperate Oceanic (TO) | Cool Continental (CC) |
|---|---|---|---|---|---|---|---|---|
| | Wall | Roof | Floor | Windows | (W/m²K) | Energy (kWh/yr) | Energy (kWh/yr) | Energy (kWh/yr) |
| Part 1 New build | | | | | | | | |
| Pitched Roof | 0.15 | 0.13 | 0.18 | 2.1 | 0.08 | $^{-18\%}$3789 | **4640*** | $^{+140\%}$10988 |
| Part 2 Existing build | | | | | | | | |
| PU Composite | 0.36 | 0.40 | 0.67 | 2.7 | 0.15 | $^{-18\%}$7407# | **9077#** | $^{+111\%}$19143# |
| EPS Composite | 0.47 | 0.40 | 0.67 | 2.7 | 0.15 | $^{-18\%}$7997$_{+8\%}$ | **9787**$_{+8\%}$ | $^{+109\%}$20423$_{+7\%}$ |
| SW/GW Built-up | 0.54 | 0.40 | 0.67 | 2.7 | 0.15 | $^{-18\%}$8371$_{+13\%}$ | **10237**$_{+13\%}$ | $^{+107\%}$21233$_{+11\%}$ |
| Part 3 New build | | | | | | | | |
| Flat Roof | 0.15 | 0.15 | 0.18 | 2.1 | 0.08 | $^{-18\%}$3649 | **4465** | $^{+139\%}$10660 |

[1] Source of climate data is the Photovoltaic Geographical Information System **(**PVGIS) and the data used is the 24 hr mean monthly values of external temperature and solar radiation.

[2.]Base cases in bold (UK) for comparisons of consumptions with climate variation - % values top left

[#]Base case in red (PU) for comparisons of consumptions with insulation variation - %values bottom right

**Table 24** U-values summary and BRESAP Energy calculations for space heating for three different climates

# Appendix 2

## Outline Specifications of elements

### Part 1 New Build

**Cavity wall constructions (U-value = 0.15 W $m^{-2}K^{-1}$)**

Common components:

Half brick (102.5mm) thick facing brick outer skin; 100mm dense blockwork inner skin; 13mm thick lightweight plaster; mist and 2 coats emulsion paint

With *Polyurethane insulation*:

| Density (kg $m^{-3}$) | k value [thermal conductivity, λ] (W $m^{-1}K^{-1}$) |
|---|---|
| 32 | 0.023 |

Form cavity 180mm wide with 300mm galvanised vertical twist wall ties; 180mm thick polyurethane insulation fixed in cavity.

Additional roof area for 180mm cavity over 50mm standard cavity including structure, coverings and rainwater goods
Additional foundation area for 180mm cavity over 50mm cavity including excavation, substructure and reinforced concrete slab

With *Stone Wool batt insulation*:

| Density (kg $m^{-3}$) | k value [thermal conductivity, λ] (W $m^{-1}K^{-1}$) |
|---|---|
| 39 | 0.037 |

Form cavity 270 wide with 400mm stainless steel wall ties; 270 mm thick stone wool insulation fixed in cavity
Additional roof area for 270mm cavity over 50mm cavity including structure, coverings and rainwater goods
Additional foundation area for 270mm cavity over 50mm cavity including excavation, substructure and reinforced concrete slab

With *Glass Wool batt insulation*:

| Density (kg $m^{-3}$) | k value [thermal conductivity, λ] (W $m^{-1}K^{-1}$) |
|---|---|
| 17 | 0.037 |

Form cavity 270 wide with 400mm stainless steel wall ties; 270mm thick glass wool insulation fixed in cavity
Additional roof area for 270mm cavity over 50mm cavity including structure, coverings and rainwater goods

Additional foundation area for 270mm cavity over 50mm cavity including excavation, substructure and reinforced concrete slab

**Pitched roof constructions, insulated on slope (U-value = 0.13 W $m^{-2}K^{-1}$)**

Common components:

Softwood attic rafters,100 (or 220) mm x 50mm members @600mm centres; Concrete interlocking tiles including underfelt, battens, eaves and ridges; 12.5mm plasterboard, fixed with nails, taped and filled joints for direct decoration; mist and 2 coats emulsion paint to plasterboard ceiling

With *Polyurethane insulation:*

| Density (kg $m^{-3}$) | k value [thermal conductivity, λ] (W $m^{-1}K^{-1}$) |
|---|---|
| 32 | 0.023 |

100mm polyurethane insulation laid between rafters; 90mm polyurethane insulation laid across rafters;

With *Stone Wool insulation:* to achieve a U-value 0.13 W $m^{-2}K^{-1}$ for any spacing or width or rafter

| Density (kg $m^{-3}$) | Thickness (mm) |
|---|---|
| 45 | 220mm (between rafters) λ=0.038 |
| 145 | 90mm (over rafters) λ=0.038 |

With *Glass Wool insulation*

| Density (kg $m^{-3}$) | k value [thermal conductivity, λ] (W $m^{-1}K^{-1}$) |
|---|---|
| 17 | 0.032 |

300mm glass wool insulation laid between rafters

**Ground floor constructions (U-value = 0.18 W $m^{-2}K^{-1}$)**

Common components:

200mm thick reinforced concrete ground slab; 50mm thick reinforced cement and sand screed

With *Polyurethane insulation*:
95mm thick polyurethane insulation

| Density (kg $m^{-3}$) | k value [thermal conductivity, λ] (W $m^{-1}K^{-1}$) |
|---|---|
| 32 | 0.023 |

With *Expanded Polystyrene insulation*:
185mm thick expanded polystyrene insulation

| Density (kg $m^{-3}$) | k value [thermal conductivity, λ] (W $m^{-1}K^{-1}$) |
|---|---|
| 18.5 | 0.03 |

**Part 2 Existing Building**

**Lining of existing external wall constructions (fixed thickness of 50 mm insulation)**

Common components:

Half brick (102.5mm) thick facing brick outer skin; form cavity 50 wide with galvanised vertical twist wall ties; 100mm dense blockwork inner skin.

With *Polyurethane insulation:* **Giving a wall U value of 0.36 W $m^{-2}K^{-1}$**

| Density (kg $m^{-3}$) | k value [thermal conductivity, λ] (W $m^{-1}K^{-1}$) |
|---|---|
| 32 | 0.023 |

50mm thick polyurethane insulation fixed to block wall with plaster adhesive; 12.5mm thick plasterboard; 2 coats emulsion paint.

With *Stone Wool insulation*: **Giving a wall U value of 0.54 W $m^{-2}K^{-1}$**

| Density (kg $m^{-3}$) | k value [thermal conductivity, λ] (W $m^{-1}K^{-1}$) |
|---|---|
| 39 | 0.037 |

50mm thick stone wool insulation fixed to block wall between studs; timber studs, 50mm x 50mm at 600ccs fixed to blockwork; 12.5mm thick plasterboard; 2 coats emulsion paint.

With *Glass Wool insulation*: **Giving a wall U value of 0.54 W $m^{-2}K^{-1}$**

| Density (kg $m^{-3}$) | k value [thermal conductivity, λ] (W $m^{-1}K^{-1}$) |
|---|---|
| 24 | 0.035 |
| | |

50mm thick glass wool insulation fixed to block wall between studs; timber studs, 50mm x 50mm at 600ccs fixed to blockwork; 12.5mm thick plasterboard; 2 coats emulsion paint.

With *Expanded Polystyrene insulation:* **Giving a wall U value of 0.47 W $m^{-2}K^{-1}$**

| Density (kg $m^{-3}$) | k value [thermal conductivity, λ] (W $m^{-1}K^{-1}$) |
|---|---|
| 30 | 0.034 |

50mm thick expanded polystyrene insulation fixed to block wall with plaster adhesive; 12.5mm thick plasterboard; 2 coats emulsion paint.

**Part 3 Flat roof constructions (U-value = 0.15 W $m^{-2}K^{-1}$)**

Common components:

Softwood flat roof structure; 100mm x 50mm joists, plates and strutting; 19mm thick OSB tongued and grooved boarding; vapour control layer; EPDM single ply roof membrane; 12.5mm plasterboard, fixed with nails, taped and filled joints for direct decoration; mist and 2 coats emulsion paint to plasterboard ceiling

150mm *polyurethane insulation*

| Density (kg $m^{-3}$) | k value [thermal conductivity, λ] (W $m^{-1}K^{-1}$) |
|---|---|
| 32 | 0.023 |

255mm *stone wool insulation*

| Density (kg $m^{-3}$) | k value [thermal conductivity, λ] (W $m^{-1}K^{-1}$) |
|---|---|
| 130 | 0.038 |

255mm *expanded polystyrene insulation*

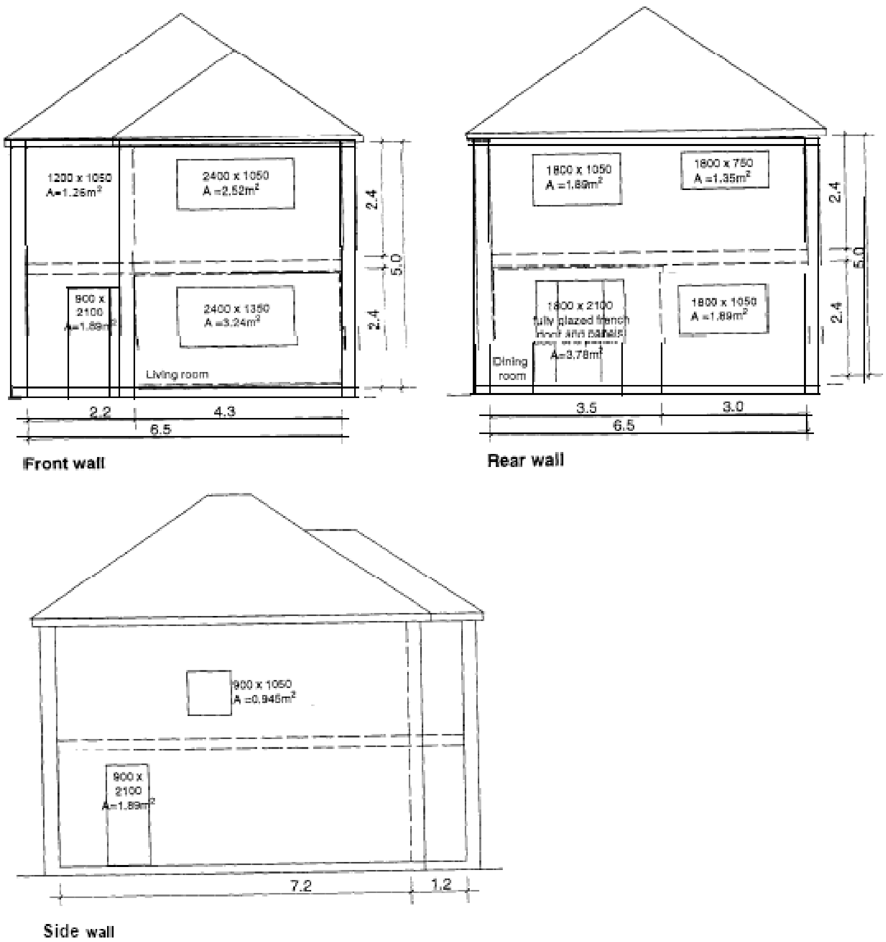
| Density (kg $m^{-3}$) | k value [thermal conductivity, λ] (W $m^{-1}K^{-1}$) |
|---|---|
| 30 | 0.034 |

## Appendix 3

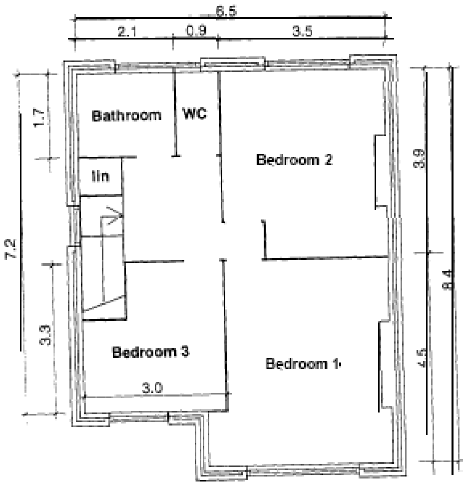
### Details of house model

**Extract from BRE Report Client Report "Standard Dwellings for Energy Modelling" (CR444/98)**

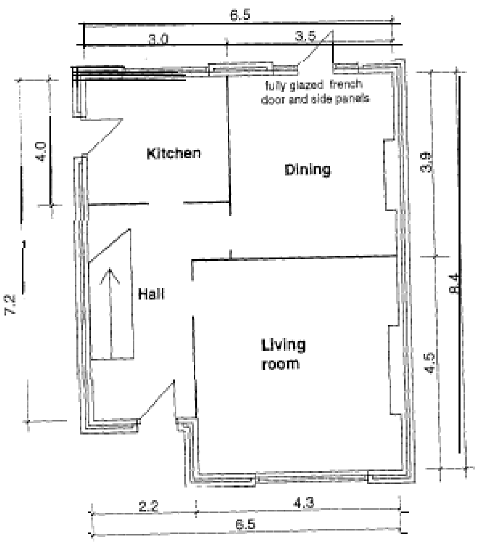
SMALL DETACHED HOUSE - ELEVATIONS



## SMALL DETACHED HOUSE




First floor




Ground floor

**SMALL DETACHED HOUSE**

Total floor area: 104.0 $m^2$

| | Total ($m^2$) | Zone 1 ($m^2$) | Storey height (m) |
|---|---|---|---|
| Ground floor | 52.0 | 26.0 | 2.4 |
| First floor | 52.0 | | 2.6 |
| Windows | 16.9 | 4.2 (incl. glazed french door) | |
| Doors | 3.8 | – | |
| Heat loss walls excl. doors/windows: | 128.3 | 32.1 | |
| Heat loss walls incl. doors/windows: | 149.0 | 36.3 | |

| | |
|---|---|
| Perimeter | 29.8 m |
| Volume | 260.00 $m^3$ |
| Occupants | 3 |

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## Appendix 4

## SAP Calculations

**SAP 2005 WORKSHEET FOR NEW DWELLING AS DESIGNED** (Version 9.82, June 2008)
**CALCULATION OF DWELLING EMISSIONS FOR REGULATIONS COMPLANCE**
**Approved Document L1A, 2006 Edition**

**Newbuild in Temperate Oceanic (TO)**

| 1. Overall dwelling dimensions | Area (m²) | Av. storey height (m) | Volume (m³) | |
|---|---|---|---|---|
| Ground floor | 52.00 | 2.40 | 124.80 | (1) |
| First floor | 52.00 | 2.60 | 135.20 | (2) |
| Total floor area | 104.00 | | | (5) |
| Dwelling volume (m³) | | | 260.00 | (6) |

| 2. Ventilation rate | | m³ per hour | ach | |
|---|---|---|---|---|
| Number of chimneys | 0 × 40 | 0 | | (7) |
| Number of flues | 0 × 20 | 0 | | (8) |
| Number of fans or passive vents | 2 × 10 | 20 | | (9) |
| Number of flueless gas fires | 0 × 40 | 0 | | (9a) |
| Infiltration due to chimneys, flues and fans | | | 0.08 | (10) |
| Pressure test | Yes | | | |
| Measured/design q50 | 10.0 | | | |
| Infiltration rate | | | 0.58 | (19) |
| Number of sides sheltered | 2 | | | (20) |
| Shelter factor | 0.85 | | | (21) |
| Adjusted infiltration rate | | | 0.49 | (22) |
| Natural ventilation | | | | |
| Effective air change rate | | | 0.62 | (25) |

3. Heat losses and heat loss parameter

| Element | Area (m²) | U-value (W/m²K) | A × U (W/K) | |
|---|---|---|---|---|
| Doors | 3.80 | 2.85 | 10.83 | (26) |
| Windows | 16.90 | (2.10) 1.94 | 32.74 | (27) |
| Ground floor | 52.00 | 0.18 | 9.36 | (28) |
| Walls | 120.80 | 0.15 | 18.12 | (29) |
| Roof | 52.00 | 0.10 | 5.20 | (30) |
| Total area of elements | 245.50 | | | (32) |
| Fabric heat loss | | | 76.25 | (33) |
| Thermal bridges (0.08 × total area) | | | 19.64 | (34) |
| Total fabric heat loss | | | 95.89 | (35) |
| Ventilation heat loss | | | 53.22 | (36) |
| Heat loss coefficient | | | 149.11 | (37) |
| Heat loss parameter (HLP) | | | 1.43 | (38) |

4. Water heating energy requirements

| | | kWh/year | |
|---|---|---|---|
| Energy content of heated water | | 2152 | (39) |
| Distribution loss | | 380 | (40) |
| Cylinder volume | 120 | | (43) |
| Cylinder loss factor (kWh/litre/day) | 0.0181 | | (44) |
| Volume factor | 1.000 | | (44a) |
| Temperature factor | 0.54 | | (44b) |
| Energy lost from cylinder in kWh/year (120 litres) | | 428 | (47) |
| Primary circuit loss | | 360 | (48) |
| Total | | 3319 | (49a) |
| Solar input | | 0 | (50) |
| Output from water heater | | 3319 | (51) |
| Heat gains from water heating | | 1472 | (52) |

5. Internal gains

| | Watts | |
|---|---|---|
| Lights, appliances, cooking and metabolic | 594 | (53) |
| Reduction in lighting gains | -22 | (53a) |
| Additional gains (Table 5a) | 10 | (53b) |
| Water heating | 168 | (54) |
| Total internal gains | 751 | (55) |

6. Solar gains

| Orientation | | Area | Flux | g | FF | Shading | | Gains (W) |
|---|---|---|---|---|---|---|---|---|
| East/West | 0.9 × | 16.90 | 50 | 0.72 | 0.70 | 0.77 | 295 | (58) |
| | | | | | | total: | 295 | (65) |

| | | |
|---|---|---|
| Total gains | 1046 | (66) |
| Gain/loss ratio | 7.01 | (67) |
| Utilisation factor | 0.923 | (68) |
| Useful gains | 966 | (69) |

7. Mean internal temperature

| | °C | |
|---|---|---|
| Mean temperature of the living area | 18.88 | (70) |
| Temperature adjustment from Table 4e | 0.00 | (71) |
| Adjustment for gains | 0.50 | (72) |
| Adjusted living area temperature | 19.38 | (73) |
| Temperature difference between zones | 1.48 | (74) |
| Living area fraction | 0.186 | (75) |
| Rest-of-house area fraction | 0.814 | (76) |
| Mean internal temperature | 18.17 | (77) |

8. Degree-days

| | | |
|---|---|---|
| Temperature rise from gains | 6.48 | (78) |
| Base temperature | 11.70 | (79) |
| Degree-days | 1281.1 | (80) |

| 9a. Energy requirements | | | kWh/year | |
|---|---|---|---|---|
| Space heating requirement (useful) | | | 3942 | (81) |
| Fraction of heat from secondary system (assumed for the calculation) | | 0.10 | | (82) |
| Efficiency of main heating system | | 90.0 | | (83) |
| Efficiency of secondary heating system | | 100 | | (84) |
| Space heating fuel (main) | | | 3942 | (85) |
| Space heating fuel (secondary) | | | 394 | (85a) |
| Water heating requirement | 3319 | | | |
| Efficiency of water heater | | 90.0 | | (86) |
| Water heating fuel | | | 3688 | (86a) |
| Electricity for pumps and fans | | | 130 | (87) |
| Electricity for lighting (30% fixed LEL) | | | 821 | (87g) |

10a and 11a do not apply

| 12a. Carbon dioxide emissions | Energy (kWh/year) | Emission factor | Emissions (kg/year) | |
|---|---|---|---|---|
| Space heating, main - box (85) | 3942 | 0.194 | 765 | (101) |
| Space heating, secondary - box (85a) | 394 | 0.422 | 166 | (102) |
| Water heating - box (86a) | 3688 | 0.194 | 716 | (103) |
| Space and water heating | | | 1647 | (107) |
| Pumps and fans - box (87) | 130 | 0.422 | 55 | (108) |
| Electricity for lighting | 821 | 0.422 | 346 | (109) |
| Total kg/year | | | 2048 | (112) |
| | | | kg/m²/year | |
| **Dwelling Carbon Dioxide Emission Rate (DER)** | | | **19.69** | (113) |

**SAP 2005 WORKSHEET FOR NEW DWELLING AS DESIGNED** (Version 9.82, June 2008)
**CALCULATION OF DWELLING EMISSIONS FOR REGULATIONS COMPLANCE**
**Approved Document L1A, 2006 Edition**

**Newbuild in Temperate Mediterranean (TM)**

1. Overall dwelling dimensions

| | Area ($m^2$) | Av. storey height (m) | Volume ($m^3$) | |
|---|---|---|---|---|
| Ground floor | 52.00 | 2.40 | 124.80 | (1) |
| First floor | 52.00 | 2.60 | 135.20 | (2) |
| Total floor area | 104.00 | | | (5) |
| Dwelling volume ($m^3$) | | | 260.00 | (6) |

2. Ventilation rate

| | | m³ per hour | ach | |
|---|---|---|---|---|
| Number of chimneys | 0 × 40 | 0 | | (7) |
| Number of flues | 0 × 20 | 0 | | (8) |
| Number of fans or passive vents | 2 × 10 | 20 | | (9) |
| Number of flueless gas fires | 0 × 40 | 0 | | (9a) |
| Infiltration due to chimneys, flues and fans | | | 0.08 | (10) |
| Pressure test | Yes | | | |
| Measured/design q50 | 10.0 | | | |
| Infiltration rate | | | 0.58 | (19) |
| Number of sides sheltered | 2 | | | (20) |
| Shelter factor | 0.85 | | | (21) |
| Adjusted infiltration rate | | | 0.49 | (22) |
| Natural ventilation | | | | |
| Effective air change rate | | | 0.62 | (25) |

3. Heat losses and heat loss parameter

| Element | Area ($m^2$) | U-value ($W/m^2K$) | A × U (W/K) | |
|---|---|---|---|---|
| Doors | 3.80 | 2.85 | 10.83 | (26) |
| Windows | 16.90 | (2.10) 1.94 | 32.74 | (27) |
| Ground floor | 52.00 | 0.18 | 9.36 | (28) |
| Walls | 120.80 | 0.15 | 18.12 | (29) |
| Roof | 52.00 | 0.10 | 5.20 | (30) |
| Total area of elements | 245.50 | | | (32) |
| Fabric heat loss | | | 76.25 | (33) |
| Thermal bridges (0.08 × total area) | | | 19.64 | (34) |
| Total fabric heat loss | | | 95.89 | (35) |
| Ventilation heat loss | | | 53.22 | (36) |
| Heat loss coefficient | | | 149.11 | (37) |
| Heat loss parameter (HLP) | | | 1.43 | (38) |

4. Water heating energy requirements

| | | kWh/year | |
|---|---|---|---|
| Energy content of heated water | | 2152 | (39) |
| Distribution loss | | 380 | (40) |
| Cylinder volume | 120 | | (43) |
| Cylinder loss factor (kWh/litre/day) | 0.0181 | | (44) |
| Volume factor | 1.000 | | (44a) |
| Temperature factor | 0.54 | | (44b) |
| Energy lost from cylinder in kWh/year (120 litres) | | 428 | (47) |
| Primary circuit loss | | 360 | (48) |
| Total | | 3319 | (49a) |
| Solar input | | 0 | (50) |
| Output from water heater | | 3319 | (51) |
| Heat gains from water heating | | 1472 | (52) |

5. Internal gains

| | Watts | |
|---|---|---|
| Lights, appliances, cooking and metabolic | 594 | (53) |
| Reduction in lighting gains | -22 | (53a) |
| Additional gains (Table 5a) | 10 | (53b) |
| Water heating | 168 | (54) |
| Total internal gains | 751 | (55) |

6. Solar gains

| Orientation | | Area | Flux | g | FF | Shading | | Gains (W) |
|---|---|---|---|---|---|---|---|---|
| East/West | 0.9 × | 16.90 | 68 | 0.72 | 0.70 | 0.77 | 401 | (58) |
| | | | | | | total: | 401 | (65) |

| | | |
|---|---|---|
| Total gains | 1152 | (66) |
| Gain/loss ratio | 7.73 | (67) |
| Utilisation factor | 0.903 | (68) |
| Useful gains | 1040 | (69) |

7. Mean internal temperature

| | °C | |
|---|---|---|
| Mean temperature of the living area | 18.88 | (70) |
| Temperature adjustment from Table 4e | 0.00 | (71) |
| Adjustment for gains | 0.59 | (72) |
| Adjusted living area temperature | 19.47 | (73) |
| Temperature difference between zones | 1.48 | (74) |
| Living area fraction | 0.186 | (75) |
| Rest-of-house area fraction | 0.814 | (76) |
| Mean internal temperature | 18.27 | (77) |

8. Degree-days

| | | |
|---|---|---|
| Temperature rise from gains | 6.97 | (78) |
| Base temperature | 11.30 | (79) |
| Degree-days | 1199.2 | (80) |

| 9a. Energy requirements | | | kWh/year | |
|---|---|---|---|---|
| Space heating requirement (useful) | | | 3222 | (81) |
| Fraction of heat from secondary system (assumed for the calculation) | | 0.10 | | (82) |
| Efficiency of main heating system | | 90.0 | | (83) |
| Efficiency of secondary heating system | | 100 | | (84) |
| Space heating fuel (main) | | | 3222 | (85) |
| Space heating fuel (secondary) | | | 322 | (85a) |
| Water heating requirement | 3319 | | | |
| Efficiency of water heater | | 90.0 | | (86) |
| Water heating fuel | | | 3688 | (86a) |
| Electricity for pumps and fans | | | 130 | (87) |
| Electricity for lighting (30% fixed LEL) | | | 821 | (87g) |

10a and 11a do not apply

| 12a. Carbon dioxide emissions | Energy (kWh/year) | Emission factor | Emissions (kg/year) | |
|---|---|---|---|---|
| Space heating, main - box (85) | 3222 | 0.194 | 625 | (101) |
| Space heating, secondary - box (85a) | 322 | 0.422 | 136 | (102) |
| Water heating - box (86a) | 3688 | 0.194 | 716 | (103) |
| Space and water heating | | | 1477 | (107) |
| Pumps and fans - box (87) | 130 | 0.422 | 55 | (108) |
| Electricity for lighting | 821 | 0.422 | 346 | (109) |
| Total kg/year | | | 1878 | (112) |
| | | | kg/m²/year | |
| **Dwelling Carbon Dioxide Emission Rate (DER)** | | | **18.06** | (113) |

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**CALCULATION OF DWELLING EMISSIONS FOR REGULATIONS COMPLANCE**
**Approved Document L1A, 2006 Edition**

**Newbuild in Cool Continental (CC)**

1. Overall dwelling dimensions

| | Area ($m^2$) | Av. storey height (m) | Volume ($m^3$) | |
|---|---|---|---|---|
| Ground floor | 52.00 | 2.40 | 124.80 | (1) |
| First floor | 52.00 | 2.60 | 135.20 | (2) |
| Total floor area | 104.00 | | | (5) |
| Dwelling volume ($m^3$) | | | 260.00 | (6) |

2. Ventilation rate

| | | $m^3$ per hour | ach | |
|---|---|---|---|---|
| Number of chimneys | 0 × 40 | 0 | | (7) |
| Number of flues | 0 × 20 | 0 | | (8) |
| Number of fans or passive vents | 2 × 10 | 20 | | (9) |
| Number of flueless gas fires | 0 × 40 | 0 | | (9a) |
| Infiltration due to chimneys, flues and fans | | | 0.08 | (10) |
| Pressure test | Yes | | | |
| Measured/design q50 | 10.0 | | | |
| Infiltration rate | | | 0.58 | (19) |
| Number of sides sheltered | 2 | | | (20) |
| Shelter factor | 0.85 | | | (21) |
| Adjusted infiltration rate | | | 0.49 | (22) |
| Natural ventilation | | | | |
| Effective air change rate | | | 0.62 | (25) |

3. Heat losses and heat loss parameter

| Element | Area ($m^2$) | U-value ($W/m^2K$) | A × U (W/K) | |
|---|---|---|---|---|
| Doors | 3.80 | 2.85 | 10.83 | (26) |
| Windows | 16.90 | (2.10) 1.94 | 32.74 | (27) |
| Ground floor | 52.00 | 0.18 | 9.36 | (28) |
| Walls | 120.80 | 0.15 | 18.12 | (29) |
| Roof | 52.00 | 0.10 | 5.20 | (30) |
| Total area of elements | 245.50 | | | (32) |
| Fabric heat loss | | | 76.25 | (33) |
| Thermal bridges (0.08 × total area) | | | 19.64 | (34) |
| Total fabric heat loss | | | 95.89 | (35) |
| Ventilation heat loss | | | 53.22 | (36) |
| Heat loss coefficient | | | 149.11 | (37) |
| Heat loss parameter (HLP) | | | 1.43 | (38) |

4. Water heating energy requirements

| | | kWh/year | |
|---|---|---|---|
| Energy content of heated water | | 2152 | (39) |
| Distribution loss | | 380 | (40) |
| Cylinder volume | 120 | | (43) |
| Cylinder loss factor (kWh/litre/day) | 0.0181 | | (44) |
| Volume factor | 1.000 | | (44a) |
| Temperature factor | 0.54 | | (44b) |
| Energy lost from cylinder in kWh/year (120 litres) | | 428 | (47) |
| Primary circuit loss | | 360 | (48) |
| Total | | 3319 | (49a) |
| Solar input | | 0 | (50) |
| Output from water heater | | 3319 | (51) |
| Heat gains from water heating | | 1472 | (52) |

5. Internal gains

| | Watts | |
|---|---|---|
| Lights, appliances, cooking and metabolic | 594 | (53) |
| Reduction in lighting gains | -22 | (53a) |
| Additional gains (Table 5a) | 10 | (53b) |
| Water heating | 168 | (54) |
| Total internal gains | 751 | (55) |

6. Solar gains

| Orientation | | Area | Flux | g | FF | Shading | | Gains (W) |
|---|---|---|---|---|---|---|---|---|
| East/West | 0.9 × | 16.90 | 46 | 0.72 | 0.70 | 0.77 | 272 | (58) |
| | | | | | | total: | 272 | (65) |

| | | |
|---|---|---|
| Total gains | 1022 | (66) |
| Gain/loss ratio | 6.86 | (67) |
| Utilisation factor | 0.928 | (68) |
| Useful gains | 948 | (69) |

7. Mean internal temperature

| | °C | |
|---|---|---|
| Mean temperature of the living area | 18.88 | (70) |
| Temperature adjustment from Table 4e | 0.00 | (71) |
| Adjustment for gains | 0.47 | (72) |
| Adjusted living area temperature | 19.35 | (73) |
| Temperature difference between zones | 1.48 | (74) |
| Living area fraction | 0.186 | (75) |
| Rest-of-house area fraction | 0.814 | (76) |
| Mean internal temperature | 18.15 | (77) |

8. Degree-days

| | | |
|---|---|---|
| Temperature rise from gains | 6.36 | (78) |
| Base temperature | 11.79 | (79) |
| Degree-days | 1300.5 | (80) |

| 9a. Energy requirements | | | kWh/year | |
|---|---|---|---|---|
| Space heating requirement (useful) | | | 9470 | (81) |
| Fraction of heat from secondary system (assumed for the calculation) | | 0.10 | | (82) |
| Efficiency of main heating system | | 90.0 | | (83) |
| Efficiency of secondary heating system | | 100 | | (84) |
| Space heating fuel (main) | | | 9470 | (85) |
| Space heating fuel (secondary) | | | 947 | (85a) |
| Water heating requirement | 3319 | | | |
| Efficiency of water heater | | 90.0 | | (86) |
| Water heating fuel | | | 3688 | (86a) |
| Electricity for pumps and fans | | | 130 | (87) |
| Electricity for lighting (30% fixed LEL) | | | 821 | (87g) |

10a and 11a do not apply

| 12a. Carbon dioxide emissions | Energy (kWh/year) | Emission factor | Emissions (kg/year) | |
|---|---|---|---|---|
| Space heating, main - box (85) | 9470 | 0.194 | 1837 | (101) |
| Space heating, secondary - box (85a) | 947 | 0.422 | 400 | (102) |
| Water heating - box (86a) | 3688 | 0.194 | 716 | (103) |
| Space and water heating | | | 2952 | (107) |
| Pumps and fans - box (87) | 130 | 0.422 | 55 | (108) |
| Electricity for lighting | 821 | 0.422 | 346 | (109) |
| Total kg/year | | | 3354 | (112) |
| | | | kg/m²/year | |
| **Dwelling Carbon Dioxide Emission Rate (DER)** | | | **32.25** | (113) |

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**Approved Document L1A, 2006 Edition**

**Bing Part2 Existing SW_GW in Temperate Oceanic (TO)**

| 1. Overall dwelling dimensions | Area ($m^2$) | Av. storey height (m) | Volume ($m^3$) | |
|---|---|---|---|---|
| Ground floor | 52.00 | 2.40 | 124.80 | (1) |
| First floor | 52.00 | 2.60 | 135.20 | (2) |
| Total floor area | 104.00 | | | (5) |
| Dwelling volume ($m^3$) | | | 260.00 | (6) |

| 2. Ventilation rate | | m³ per hour | ach | |
|---|---|---|---|---|
| Number of chimneys | 0 × 40 | 0 | | (7) |
| Number of flues | 0 × 20 | 0 | | (8) |
| Number of fans or passive vents | 2 × 10 | 20 | | (9) |
| Number of flueless gas fires | 0 × 40 | 0 | | (9a) |
| Infiltration due to chimneys, flues and fans | | | 0.08 | (10) |
| Pressure test | Yes | | | |
| Measured/design q50 | 10.0 | | | |
| Infiltration rate | | | 0.58 | (19) |
| Number of sides sheltered | 2 | | | (20) |
| Shelter factor | 0.85 | | | (21) |
| Adjusted infiltration rate | | | 0.49 | (22) |
| Natural ventilation | | | | |
| Effective air change rate | | | 0.62 | (25) |

3. Heat losses and heat loss parameter

| Element | Area ($m^2$) | U-value ($W/m^2K$) | A × U (W/K) | |
|---|---|---|---|---|
| Doors | 3.80 | 2.85 | 10.83 | (26) |
| Windows | 16.90 | (2.70) 2.44 | 41.18 | (27) |
| Ground floor | 52.00 | 0.67 | 34.84 | (28) |
| Walls | 120.80 | 0.54 | 65.23 | (29) |
| Roof | 52.00 | 0.40 | 20.80 | (30) |
| Total area of elements | 245.50 | | | (32) |
| Fabric heat loss | | | 172.88 | (33) |
| Thermal bridges (0.15 × total area) | | | 36.83 | (34) |
| Total fabric heat loss | | | 209.71 | (35) |
| Ventilation heat loss | | | 53.22 | (36) |
| Heat loss coefficient | | | 262.93 | (37) |
| Heat loss parameter (HLP) | | | 2.53 | (38) |

4. Water heating energy requirements

| | | kWh/year | |
|---|---|---|---|
| Energy content of heated water | | 2152 | (39) |
| Distribution loss | | 380 | (40) |
| Cylinder volume | 120 | | (43) |
| Cylinder loss factor (kWh/litre/day) | 0.0181 | | (44) |
| Volume factor | 1.000 | | (44a) |
| Temperature factor | 0.54 | | (44b) |
| Energy lost from cylinder in kWh/year (120 litres) | | 428 | (47) |
| Primary circuit loss | | 360 | (48) |
| Total | | 3319 | (49a) |
| Solar input | | 0 | (50) |
| Output from water heater | | 3319 | (51) |
| Heat gains from water heating | | 1472 | (52) |

5. Internal gains

| | Watts | |
|---|---|---|
| Lights, appliances, cooking and metabolic | 594 | (53) |
| Reduction in lighting gains | -22 | (53a) |
| Additional gains (Table 5a) | 10 | (53b) |
| Water heating | 168 | (54) |
| Total internal gains | 751 | (55) |

6. Solar gains

| Orientation | | Area | Flux | g | FF | Shading | | Gains (W) |
|---|---|---|---|---|---|---|---|---|
| East/West | 0.9 × | 16.90 | 50 | 0.76 | 0.70 | 0.77 | 312 | (58) |
| | | | | | | total: | 312 | (65) |

| | | |
|---|---|---|
| Total gains | 1062 | (66) |
| Gain/loss ratio | 4.04 | (67) |
| Utilisation factor | 0.988 | (68) |
| Useful gains | 1050 | (69) |

7. Mean internal temperature

| | °C | |
|---|---|---|
| Mean temperature of the living area | 18.81 | (70) |
| Temperature adjustment from Table 4e | 0.00 | (71) |
| Adjustment for gains | 0.00 | (72) |
| Adjusted living area temperature | 18.80 | (73) |
| Temperature difference between zones | 1.65 | (74) |
| Living area fraction | 0.186 | (75) |
| Rest-of-house area fraction | 0.814 | (76) |
| Mean internal temperature | 17.46 | (77) |

8. Degree-days

| | | |
|---|---|---|
| Temperature rise from gains | 3.99 | (78) |
| Base temperature | 13.47 | (79) |
| Degree-days | 1662.4 | (80) |

| 9a. Energy requirements | | | kWh/year | |
|---|---|---|---|---|
| Space heating requirement (useful) | | | 9306 | (81) |
| Fraction of heat from secondary system (assumed for the calculation) | | 0.10 | | (82) |
| Efficiency of main heating system | | 90.0 | | (83) |
| Efficiency of secondary heating system | | 100 | | (84) |
| Space heating fuel (main) | | | 9306 | (85) |
| Space heating fuel (secondary) | | | 931 | (85a) |
| Water heating requirement | 3319 | | | |
| Efficiency of water heater | | 90.0 | | (86) |
| Water heating fuel | | | 3688 | (86a) |
| Electricity for pumps and fans | | | 130 | (87) |
| Electricity for lighting (30% fixed LEL) | | | 821 | (87g) |

10a and 11a do not apply

| 12a. Carbon dioxide emissions | Energy (kWh/year) | Emission factor | Emissions (kg/year) | |
|---|---|---|---|---|
| Space heating, main - box (85) | 9306 | 0.194 | 1805 | (101) |
| Space heating, secondary - box (85a) | 931 | 0.422 | 393 | (102) |
| Water heating - box (86a) | 3688 | 0.194 | 716 | (103) |
| Space and water heating | | | 2914 | (107) |
| Pumps and fans - box (87) | 130 | 0.422 | 55 | (108) |
| Electricity for lighting | 821 | 0.422 | 346 | (109) |
| Total kg/year | | | 3315 | (112) |
| | | | kg/m²/year | |
| **Dwelling Carbon Dioxide Emission Rate (DER)** | | | **31.87** | (113) |

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**Approved Document L1A, 2006 Edition**

**Bing Part2 Existing SW_GW in Temperate Mediterranean (TM)**

1. Overall dwelling dimensions

| | Area ($m^2$) | Av. storey height (m) | Volume ($m^3$) | |
|---|---|---|---|---|
| Ground floor | 52.00 | 2.40 | 124.80 | (1) |
| First floor | 52.00 | 2.60 | 135.20 | (2) |
| Total floor area | 104.00 | | | (5) |
| Dwelling volume ($m^3$) | | | 260.00 | (6) |

2. Ventilation rate

| | | m³ per hour | ach | |
|---|---|---|---|---|
| Number of chimneys | 0 × 40 | 0 | | (7) |
| Number of flues | 0 × 20 | 0 | | (8) |
| Number of fans or passive vents | 2 × 10 | 20 | | (9) |
| Number of flueless gas fires | 0 × 40 | 0 | | (9a) |
| Infiltration due to chimneys, flues and fans | | | 0.08 | (10) |
| Pressure test | Yes | | | |
| Measured/design q50 | 10.0 | | | |
| Infiltration rate | | | 0.58 | (19) |
| Number of sides sheltered | 2 | | | (20) |
| Shelter factor | 0.85 | | | (21) |
| Adjusted infiltration rate | | | 0.49 | (22) |
| Natural ventilation | | | | |
| Effective air change rate | | | 0.62 | (25) |

3. Heat losses and heat loss parameter

| Element | Area ($m^2$) | U-value ($W/m^2K$) | A × U (W/K) | |
|---|---|---|---|---|
| Doors | 3.80 | 2.85 | 10.83 | (26) |
| Windows | 16.90 | (2.70) 2.44 | 41.18 | (27) |
| Ground floor | 52.00 | 0.67 | 34.84 | (28) |
| Walls | 120.80 | 0.54 | 65.23 | (29) |
| Roof | 52.00 | 0.40 | 20.80 | (30) |
| Total area of elements | 245.50 | | | (32) |
| Fabric heat loss | | | 172.88 | (33) |
| Thermal bridges (0.15 × total area) | | | 36.83 | (34) |
| Total fabric heat loss | | | 209.71 | (35) |
| Ventilation heat loss | | | 53.22 | (36) |
| Heat loss coefficient | | | 262.93 | (37) |
| Heat loss parameter (HLP) | | | 2.53 | (38) |

4. Water heating energy requirements

| | | kWh/year | |
|---|---|---|---|
| Energy content of heated water | | 2152 | (39) |
| Distribution loss | | 380 | (40) |
| Cylinder volume | 120 | | (43) |
| Cylinder loss factor (kWh/litre/day) | 0.0181 | | (44) |
| Volume factor | 1.000 | | (44a) |
| Temperature factor | 0.54 | | (44b) |
| Energy lost from cylinder in kWh/year (120 litres) | | 428 | (47) |
| Primary circuit loss | | 360 | (48) |
| Total | | 3319 | (49a) |
| Solar input | | 0 | (50) |
| Output from water heater | | 3319 | (51) |
| Heat gains from water heating | | 1472 | (52) |

5. Internal gains

| | Watts | |
|---|---|---|
| Lights, appliances, cooking and metabolic | 594 | (53) |
| Reduction in lighting gains | -22 | (53a) |
| Additional gains (Table 5a) | 10 | (53b) |
| Water heating | 168 | (54) |
| Total internal gains | 751 | (55) |

6. Solar gains

| Orientation | | Area | Flux | g | FF | Shading | | Gains (W) |
|---|---|---|---|---|---|---|---|---|
| East/West | 0.9 × | 16.90 | 68 | 0.76 | 0.70 | 0.77 | 424 | (58) |
| | | | | | | total: | 424 | (65) |

| | | |
|---|---|---|
| Total gains | 1174 | (66) |
| Gain/loss ratio | 4.47 | (67) |
| Utilisation factor | 0.982 | (68) |
| Useful gains | 1154 | (69) |

| 7. Mean internal temperature | °C | |
|---|---|---|
| Mean temperature of the living area | 18.81 | (70) |
| Temperature adjustment from Table 4e | 0.00 | (71) |
| Adjustment for gains | 0.08 | (72) |
| Adjusted living area temperature | 18.88 | (73) |
| Temperature difference between zones | 1.65 | (74) |
| Living area fraction | 0.186 | (75) |
| Rest-of-house area fraction | 0.814 | (76) |
| Mean internal temperature | 17.54 | (77) |

8. Degree-days

| | | |
|---|---|---|
| Temperature rise from gains | 4.39 | (78) |
| Base temperature | 13.15 | (79) |
| Degree-days | 1593.0 | (80) |

| 9a. Energy requirements | | | kWh/year | |
|---|---|---|---|---|
| Space heating requirement (useful) | | | 7610 | (81) |
| Fraction of heat from secondary system (assumed for the calculation) | | 0.10 | | (82) |
| Efficiency of main heating system | | 90.0 | | (83) |
| Efficiency of secondary heating system | | 100 | | (84) |
| Space heating fuel (main) | | | 7610 | (85) |
| Space heating fuel (secondary) | | | 761 | (85a) |
| Water heating requirement | 3319 | | | |
| Efficiency of water heater | | 90.0 | | (86) |
| Water heating fuel | | | 3688 | (86a) |
| Electricity for pumps and fans | | | 130 | (87) |
| Electricity for lighting (30% fixed LEL) | | | 821 | (87g) |

10a and 11a do not apply

| 12a. Carbon dioxide emissions | Energy (kWh/year) | Emission factor | Emissions (kg/year) | |
|---|---|---|---|---|
| Space heating, main - box (85) | 7610 | 0.194 | 1476 | (101) |
| Space heating, secondary - box (85a) | 761 | 0.422 | 321 | (102) |
| Water heating - box (86a) | 3688 | 0.194 | 716 | (103) |
| Space and water heating | | | 2513 | (107) |
| Pumps and fans - box (87) | 130 | 0.422 | 55 | (108) |
| Electricity for lighting | 821 | 0.422 | 346 | (109) |
| Total kg/year | | | 2914 | (112) |
| | | | kg/m²/year | |
| **Dwelling Carbon Dioxide Emission Rate (DER)** | | | **28.02** | (113) |

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**Approved Document L1A, 2006 Edition**

**Bing Part2 Existing SW_GW in Cool Continental (CC)**

1. Overall dwelling dimensions

| | Area ($m^2$) | Av. storey height (m) | Volume ($m^3$) | |
|---|---|---|---|---|
| Ground floor | 52.00 | 2.40 | 124.80 | (1) |
| First floor | 52.00 | 2.60 | 135.20 | (2) |
| Total floor area | 104.00 | | | (5) |
| Dwelling volume ($m^3$) | | | 260.00 | (6) |

2. Ventilation rate

| | | $m^3$ per hour | ach | |
|---|---|---|---|---|
| Number of chimneys | 0 × 40 | 0 | | (7) |
| Number of flues | 0 × 20 | 0 | | (8) |
| Number of fans or passive vents | 2 × 10 | 20 | | (9) |
| Number of flueless gas fires | 0 × 40 | 0 | | (9a) |
| Infiltration due to chimneys, flues and fans | | | 0.08 | (10) |
| Pressure test | Yes | | | |
| Measured/design q50 | 10.0 | | | |
| Infiltration rate | | | 0.58 | (19) |
| Number of sides sheltered | 2 | | | (20) |
| Shelter factor | 0.85 | | | (21) |
| Adjusted infiltration rate | | | 0.49 | (22) |
| Natural ventilation | | | | |
| Effective air change rate | | | 0.62 | (25) |

3. Heat losses and heat loss parameter

| Element | Area ($m^2$) | U-value ($W/m^2K$) | A × U (W/K) | |
|---|---|---|---|---|
| Doors | 3.80 | 2.85 | 10.83 | (26) |
| Windows | 16.90 | (2.70) 2.44 | 41.18 | (27) |
| Ground floor | 52.00 | 0.67 | 34.84 | (28) |
| Walls | 120.80 | 0.54 | 65.23 | (29) |
| Roof | 52.00 | 0.40 | 20.80 | (30) |
| Total area of elements | 245.50 | | | (32) |
| Fabric heat loss | | | 172.88 | (33) |
| Thermal bridges (0.15 × total area) | | | 36.83 | (34) |
| Total fabric heat loss | | | 209.71 | (35) |
| Ventilation heat loss | | | 53.22 | (36) |
| Heat loss coefficient | | | 262.93 | (37) |
| Heat loss parameter (HLP) | | | 2.53 | (38) |

4. Water heating energy requirements

| | | kWh/year | |
|---|---|---|---|
| Energy content of heated water | | 2152 | (39) |
| Distribution loss | | 380 | (40) |
| Cylinder volume | 120 | | (43) |
| Cylinder loss factor (kWh/litre/day) | 0.0181 | | (44) |
| Volume factor | 1.000 | | (44a) |
| Temperature factor | 0.54 | | (44b) |
| Energy lost from cylinder in kWh/year (120 litres) | | 428 | (47) |
| Primary circuit loss | | 360 | (48) |
| Total | | 3319 | (49a) |
| Solar input | | 0 | (50) |
| Output from water heater | | 3319 | (51) |
| Heat gains from water heating | | 1472 | (52) |

5. Internal gains

| | Watts | |
|---|---|---|
| Lights, appliances, cooking and metabolic | 594 | (53) |
| Reduction in lighting gains | -22 | (53a) |
| Additional gains (Table 5a) | 10 | (53b) |
| Water heating | 168 | (54) |
| Total internal gains | 751 | (55) |

6. Solar gains

| Orientation | | Area | Flux | g | FF | Shading | | Gains (W) |
|---|---|---|---|---|---|---|---|---|
| East/West | 0.9 × | 16.90 | 46 | 0.76 | 0.70 | 0.77 | 287 | (58) |
| | | | | | | total: | 287 | (65) |

| | | |
|---|---|---|
| Total gains | 1037 | (66) |
| Gain/loss ratio | 3.95 | (67) |
| Utilisation factor | 0.990 | (68) |
| Useful gains | 1027 | (69) |

| 7. Mean internal temperature | °C | |
|---|---|---|
| Mean temperature of the living area | 18.81 | (70) |
| Temperature adjustment from Table 4e | 0.00 | (71) |
| Adjustment for gains | -0.02 | (72) |
| Adjusted living area temperature | 18.79 | (73) |
| Temperature difference between zones | 1.65 | (74) |
| Living area fraction | 0.186 | (75) |
| Rest-of-house area fraction | 0.814 | (76) |
| Mean internal temperature | 17.44 | (77) |

8. Degree-days

| | | |
|---|---|---|
| Temperature rise from gains | 3.90 | (78) |
| Base temperature | 13.54 | (79) |
| Degree-days | 1678.0 | (80) |

| 9a. Energy requirements | | | kWh/year | |
|---|---|---|---|---|
| Space heating requirement (useful) | | | 19303 | (81) |
| Fraction of heat from secondary system (assumed for the calculation) | | 0.10 | | (82) |
| Efficiency of main heating system | | 90.0 | | (83) |
| Efficiency of secondary heating system | | 100 | | (84) |
| Space heating fuel (main) | | | 19303 | (85) |
| Space heating fuel (secondary) | | | 1930 | (85a) |
| Water heating requirement | 3319 | | | |
| Efficiency of water heater | | 90.0 | | (86) |
| Water heating fuel | | | 3688 | (86a) |
| Electricity for pumps and fans | | | 130 | (87) |
| Electricity for lighting (30% fixed LEL) | | | 821 | (87g) |

10a and 11a do not apply

| 12a. Carbon dioxide emissions | Energy (kWh/year) | Emission factor | Emissions (kg/year) | |
|---|---|---|---|---|
| Space heating, main - box (85) | 19303 | 0.194 | 3745 | (101) |
| Space heating, secondary - box (85a) | 1930 | 0.422 | 815 | (102) |
| Water heating - box (86a) | 3688 | 0.194 | 716 | (103) |
| Space and water heating | | | 5275 | (107) |
| Pumps and fans - box (87) | 130 | 0.422 | 55 | (108) |
| Electricity for lighting | 821 | 0.422 | 346 | (109) |
| Total kg/year | | | 5676 | (112) |
| | | | kg/m²/year | |
| **Dwelling Carbon Dioxide Emission Rate (DER)** | | | **54.58** | (113) |

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**Bing Part2 Existing PU in Temperate Oceanic (TO)**

| 1. Overall dwelling dimensions | Area ($m^2$) | Av. storey height (m) | Volume ($m^3$) | |
|---|---|---|---|---|
| Ground floor | 52.00 | 2.40 | 124.80 | (1) |
| First floor | 52.00 | 2.60 | 135.20 | (2) |
| Total floor area | 104.00 | | | (5) |
| Dwelling volume ($m^3$) | | | 260.00 | (6) |

2. Ventilation rate

| | | m³ per hour | ach | |
|---|---|---|---|---|
| Number of chimneys | 0 × 40 | 0 | | (7) |
| Number of flues | 0 × 20 | 0 | | (8) |
| Number of fans or passive vents | 2 × 10 | 20 | | (9) |
| Number of flueless gas fires | 0 × 40 | 0 | | (9a) |
| Infiltration due to chimneys, flues and fans | | | 0.08 | (10) |
| Pressure test | Yes | | | |
| Measured/design q50 | 10.0 | | | |
| Infiltration rate | | | 0.58 | (19) |
| Number of sides sheltered | 2 | | | (20) |
| Shelter factor | 0.85 | | | (21) |
| Adjusted infiltration rate | | | 0.49 | (22) |
| Natural ventilation | | | | |
| Effective air change rate | | | 0.62 | (25) |

3. Heat losses and heat loss parameter

| Element | Area ($m^2$) | U-value ($W/m^2K$) | A × U (W/K) | |
|---|---|---|---|---|
| Doors | 3.80 | 2.85 | 10.83 | (26) |
| Windows | 16.90 | (2.70) 2.44 | 41.18 | (27) |
| Ground floor | 52.00 | 0.67 | 34.84 | (28) |
| Walls | 120.80 | 0.36 | 43.49 | (29) |
| Roof | 52.00 | 0.40 | 20.80 | (30) |
| Total area of elements | 245.50 | | | (32) |
| Fabric heat loss | | | 151.14 | (33) |
| Thermal bridges (0.15 × total area) | | | 36.83 | (34) |
| Total fabric heat loss | | | 187.97 | (35) |
| Ventilation heat loss | | | 53.22 | (36) |
| Heat loss coefficient | | | 241.18 | (37) |
| Heat loss parameter (HLP) | | | 2.32 | (38) |

4. Water heating energy requirements

| | | kWh/year | |
|---|---|---|---|
| Energy content of heated water | | 2152 | (39) |
| Distribution loss | | 380 | (40) |
| Cylinder volume | 120 | | (43) |
| Cylinder loss factor (kWh/litre/day) | 0.0181 | | (44) |
| Volume factor | 1.000 | | (44a) |
| Temperature factor | 0.54 | | (44b) |
| Energy lost from cylinder in kWh/year (120 litres) | | 428 | (47) |
| Primary circuit loss | | 360 | (48) |
| Total | | 3319 | (49a) |
| Solar input | | 0 | (50) |
| Output from water heater | | 3319 | (51) |
| Heat gains from water heating | | 1472 | (52) |

5. Internal gains

| | Watts | |
|---|---|---|
| Lights, appliances, cooking and metabolic | 594 | (53) |
| Reduction in lighting gains | -22 | (53a) |
| Additional gains (Table 5a) | 10 | (53b) |
| Water heating | 168 | (54) |
| Total internal gains | 751 | (55) |

6. Solar gains

| Orientation | | Area | Flux | g | FF | Shading | | Gains (W) |
|---|---|---|---|---|---|---|---|---|
| East/West | 0.9 × | 16.90 | 50 | 0.76 | 0.70 | 0.77 | 312 | (58) |
| | | | | | | total: | 312 | (65) |

| | | |
|---|---|---|
| Total gains | 1062 | (66) |
| Gain/loss ratio | 4.40 | (67) |
| Utilisation factor | 0.983 | (68) |
| Useful gains | 1044 | (69) |

| 7. Mean internal temperature | °C | |
|---|---|---|
| Mean temperature of the living area | 18.82 | (70) |
| Temperature adjustment from Table 4e | 0.00 | (71) |
| Adjustment for gains | 0.07 | (72) |
| Adjusted living area temperature | 18.89 | (73) |
| Temperature difference between zones | 1.62 | (74) |
| Living area fraction | 0.186 | (75) |
| Rest-of-house area fraction | 0.814 | (76) |
| Mean internal temperature | 17.57 | (77) |

8. Degree-days

| | | |
|---|---|---|
| Temperature rise from gains | 4.33 | (78) |
| Base temperature | 13.24 | (79) |
| Degree-days | 1612.9 | (80) |

| 9a. Energy requirements | | | kWh/year | |
|---|---|---|---|---|
| Space heating requirement (useful) | | | 8252 | (81) |
| Fraction of heat from secondary system (assumed for the calculation) | | 0.10 | | (82) |
| Efficiency of main heating system | | 90.0 | | (83) |
| Efficiency of secondary heating system | | 100 | | (84) |
| Space heating fuel (main) | | | 8252 | (85) |
| Space heating fuel (secondary) | | | 825 | (85a) |
| Water heating requirement | 3319 | | | |
| Efficiency of water heater | | 90.0 | | (86) |
| Water heating fuel | | | 3688 | (86a) |
| Electricity for pumps and fans | | | 130 | (87) |
| Electricity for lighting (30% fixed LEL) | | | 821 | (87g) |

10a and 11a do not apply

| 12a. Carbon dioxide emissions | Energy (kWh/year) | Emission factor | Emissions (kg/year) | |
|---|---|---|---|---|
| Space heating, main - box (85) | 8252 | 0.194 | 1601 | (101) |
| Space heating, secondary - box (85a) | 825 | 0.422 | 348 | (102) |
| Water heating - box (86a) | 3688 | 0.194 | 716 | (103) |
| Space and water heating | | | 2665 | (107) |
| Pumps and fans - box (87) | 130 | 0.422 | 55 | (108) |
| Electricity for lighting | 821 | 0.422 | 346 | (109) |
| Total kg/year | | | 3066 | (112) |
| | | | kg/m²/year | |
| **Dwelling Carbon Dioxide Emission Rate (DER)** | | | **29.48** | (113) |

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**Bing Part2 Existing PU in Temperate Mediterranean (TM)**

| 1. Overall dwelling dimensions | Area ($m^2$) | Av. storey height (m) | Volume ($m^3$) | |
|---|---|---|---|---|
| Ground floor | 52.00 | 2.40 | 124.80 | (1) |
| First floor | 52.00 | 2.60 | 135.20 | (2) |
| Total floor area | 104.00 | | | (5) |
| Dwelling volume ($m^3$) | | | 260.00 | (6) |

| 2. Ventilation rate | | m³ per hour | ach | |
|---|---|---|---|---|
| Number of chimneys | 0 × 40 | 0 | | (7) |
| Number of flues | 0 × 20 | 0 | | (8) |
| Number of fans or passive vents | 2 × 10 | 20 | | (9) |
| Number of flueless gas fires | 0 × 40 | 0 | | (9a) |
| Infiltration due to chimneys, flues and fans | | | 0.08 | (10) |
| Pressure test | Yes | | | |
| Measured/design q50 | 10.0 | | | |
| Infiltration rate | | | 0.58 | (19) |
| Number of sides sheltered | 2 | | | (20) |
| Shelter factor | 0.85 | | | (21) |
| Adjusted infiltration rate | | | 0.49 | (22) |
| Natural ventilation | | | | |
| Effective air change rate | | | 0.62 | (25) |

3. Heat losses and heat loss parameter

| Element | Area ($m^2$) | U-value ($W/m^2K$) | A × U (W/K) | |
|---|---|---|---|---|
| Doors | 3.80 | 2.85 | 10.83 | (26) |
| Windows | 16.90 | (2.70) 2.44 | 41.18 | (27) |
| Ground floor | 52.00 | 0.67 | 34.84 | (28) |
| Walls | 120.80 | 0.36 | 43.49 | (29) |
| Roof | 52.00 | 0.40 | 20.80 | (30) |
| Total area of elements | 245.50 | | | (32) |
| Fabric heat loss | | | 151.14 | (33) |
| Thermal bridges (0.15 × total area) | | | 36.83 | (34) |
| Total fabric heat loss | | | 187.97 | (35) |
| Ventilation heat loss | | | 53.22 | (36) |
| Heat loss coefficient | | | 241.18 | (37) |
| Heat loss parameter (HLP) | | | 2.32 | (38) |

4. Water heating energy requirements

| | | kWh/year | |
|---|---|---|---|
| Energy content of heated water | | 2152 | (39) |
| Distribution loss | | 380 | (40) |
| Cylinder volume | 120 | | (43) |
| Cylinder loss factor (kWh/litre/day) | 0.0181 | | (44) |
| Volume factor | 1.000 | | (44a) |
| Temperature factor | 0.54 | | (44b) |
| Energy lost from cylinder in kWh/year (120 litres) | | 428 | (47) |
| Primary circuit loss | | 360 | (48) |
| Total | | 3319 | (49a) |
| Solar input | | 0 | (50) |
| Output from water heater | | 3319 | (51) |
| Heat gains from water heating | | 1472 | (52) |

5. Internal gains

| | Watts | |
|---|---|---|
| Lights, appliances, cooking and metabolic | 594 | (53) |
| Reduction in lighting gains | -22 | (53a) |
| Additional gains (Table 5a) | 10 | (53b) |
| Water heating | 168 | (54) |
| Total internal gains | 751 | (55) |

6. Solar gains

| Orientation | | Area | Flux | g | FF | Shading | | Gains (W) |
|---|---|---|---|---|---|---|---|---|
| East/West | 0.9 × | 16.90 | 68 | 0.76 | 0.70 | 0.77 | 424 | (58) |
| | | | | | | total: | 424 | (65) |

| | | |
|---|---|---|
| Total gains | 1174 | (66) |
| Gain/loss ratio | 4.87 | (67) |
| Utilisation factor | 0.975 | (68) |
| Useful gains | 1145 | (69) |

7. Mean internal temperature

| | °C | |
|---|---|---|
| Mean temperature of the living area | 18.82 | (70) |
| Temperature adjustment from Table 4e | 0.00 | (71) |
| Adjustment for gains | 0.15 | (72) |
| Adjusted living area temperature | 18.97 | (73) |
| Temperature difference between zones | 1.62 | (74) |
| Living area fraction | 0.186 | (75) |
| Rest-of-house area fraction | 0.814 | (76) |
| Mean internal temperature | 17.65 | (77) |

8. Degree-days

| | | |
|---|---|---|
| Temperature rise from gains | 4.75 | (78) |
| Base temperature | 12.91 | (79) |
| Degree-days | 1539.3 | (80) |

| 9a. Energy requirements | | | kWh/year | |
|---|---|---|---|---|
| Space heating requirement (useful) | | | 6734 | (81) |
| Fraction of heat from secondary system (assumed for the calculation) | | 0.10 | | (82) |
| Efficiency of main heating system | | 90.0 | | (83) |
| Efficiency of secondary heating system | | 100 | | (84) |
| Space heating fuel (main) | | | 6734 | (85) |
| Space heating fuel (secondary) | | | 673 | (85a) |
| Water heating requirement | 3319 | | | |
| Efficiency of water heater | | 90.0 | | (86) |
| Water heating fuel | | | 3688 | (86a) |
| Electricity for pumps and fans | | | 130 | (87) |
| Electricity for lighting (30% fixed LEL) | | | 821 | (87g) |

10a and 11a do not apply

| 12a. Carbon dioxide emissions | Energy (kWh/year) | Emission factor | Emissions (kg/year) | |
|---|---|---|---|---|
| Space heating, main - box (85) | 6734 | 0.194 | 1306 | (101) |
| Space heating, secondary - box (85a) | 673 | 0.422 | 284 | (102) |
| Water heating - box (86a) | 3688 | 0.194 | 716 | (103) |
| Space and water heating | | | 2306 | (107) |
| Pumps and fans - box (87) | 130 | 0.422 | 55 | (108) |
| Electricity for lighting | 821 | 0.422 | 346 | (109) |
| Total kg/year | | | 2707 | (112) |
| | | | kg/m²/year | |
| **Dwelling Carbon Dioxide Emission Rate (DER)** | | | **26.03** | (113) |

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**Bing Part2 Existing PU in Cool Continental (CC)**

1. Overall dwelling dimensions

| | Area ($m^2$) | Av. storey height (m) | Volume ($m^3$) | |
|---|---|---|---|---|
| Ground floor | 52.00 | 2.40 | 124.80 | (1) |
| First floor | 52.00 | 2.60 | 135.20 | (2) |
| Total floor area | 104.00 | | | (5) |
| Dwelling volume ($m^3$) | | | 260.00 | (6) |

2. Ventilation rate

| | | m³ per hour | ach | |
|---|---|---|---|---|
| Number of chimneys | 0 × 40 | 0 | | (7) |
| Number of flues | 0 × 20 | 0 | | (8) |
| Number of fans or passive vents | 2 × 10 | 20 | | (9) |
| Number of flueless gas fires | 0 × 40 | 0 | | (9a) |
| Infiltration due to chimneys, flues and fans | | | 0.08 | (10) |
| Pressure test | Yes | | | |
| Measured/design q50 | 10.0 | | | |
| Infiltration rate | | | 0.58 | (19) |
| Number of sides sheltered | 2 | | | (20) |
| Shelter factor | 0.85 | | | (21) |
| Adjusted infiltration rate | | | 0.49 | (22) |
| Natural ventilation | | | | |
| Effective air change rate | | | 0.62 | (25) |

3. Heat losses and heat loss parameter

| Element | Area ($m^2$) | U-value ($W/m^2K$) | A × U (W/K) | |
|---|---|---|---|---|
| Doors | 3.80 | 2.85 | 10.83 | (26) |
| Windows | 16.90 | (2.70) 2.44 | 41.18 | (27) |
| Ground floor | 52.00 | 0.67 | 34.84 | (28) |
| Walls | 120.80 | 0.36 | 43.49 | (29) |
| Roof | 52.00 | 0.40 | 20.80 | (30) |
| Total area of elements | 245.50 | | | (32) |
| Fabric heat loss | | | 151.14 | (33) |
| Thermal bridges (0.15 × total area) | | | 36.83 | (34) |
| Total fabric heat loss | | | 187.97 | (35) |
| Ventilation heat loss | | | 53.22 | (36) |
| Heat loss coefficient | | | 241.18 | (37) |
| Heat loss parameter (HLP) | | | 2.32 | (38) |

4. Water heating energy requirements

| | | kWh/year | |
|---|---|---|---|
| Energy content of heated water | | 2152 | (39) |
| Distribution loss | | 380 | (40) |
| Cylinder volume | 120 | | (43) |
| Cylinder loss factor (kWh/litre/day) | 0.0181 | | (44) |
| Volume factor | 1.000 | | (44a) |
| Temperature factor | 0.54 | | (44b) |
| Energy lost from cylinder in kWh/year (120 litres) | | 428 | (47) |
| Primary circuit loss | | 360 | (48) |
| Total | | 3319 | (49a) |
| Solar input | | 0 | (50) |
| Output from water heater | | 3319 | (51) |
| Heat gains from water heating | | 1472 | (52) |

5. Internal gains

| | Watts | |
|---|---|---|
| Lights, appliances, cooking and metabolic | 594 | (53) |
| Reduction in lighting gains | -22 | (53a) |
| Additional gains (Table 5a) | 10 | (53b) |
| Water heating | 168 | (54) |
| Total internal gains | 751 | (55) |

6. Solar gains

| Orientation | | Area | Flux | g | FF | Shading | | Gains (W) |
|---|---|---|---|---|---|---|---|---|
| East/West | 0.9 × | 16.90 | 46 | 0.76 | 0.70 | 0.77 | 287 | (58) |
| | | | | | | total: | 287 | (65) |

| | | |
|---|---|---|
| Total gains | 1037 | (66) |
| Gain/loss ratio | 4.30 | (67) |
| Utilisation factor | 0.985 | (68) |
| Useful gains | 1022 | (69) |

7. Mean internal temperature

| | °C | |
|---|---|---|
| Mean temperature of the living area | 18.82 | (70) |
| Temperature adjustment from Table 4e | 0.00 | (71) |
| Adjustment for gains | 0.05 | (72) |
| Adjusted living area temperature | 18.87 | (73) |
| Temperature difference between zones | 1.62 | (74) |
| Living area fraction | 0.186 | (75) |
| Rest-of-house area fraction | 0.814 | (76) |
| Mean internal temperature | 17.55 | (77) |

8. Degree-days

| | | |
|---|---|---|
| Temperature rise from gains | 4.24 | (78) |
| Base temperature | 13.32 | (79) |
| Degree-days | 1629.6 | (80) |

9a. Energy requirements

| | | | kWh/year | |
|---|---|---|---|---|
| Space heating requirement (useful) | | | 17403 | (81) |
| Fraction of heat from secondary system (assumed for the calculation) | | 0.10 | | (82) |
| Efficiency of main heating system | | 90.0 | | (83) |
| Efficiency of secondary heating system | | 100 | | (84) |
| Space heating fuel (main) | | | 17403 | (85) |
| Space heating fuel (secondary) | | | 1740 | (85a) |
| Water heating requirement | 3319 | | | |
| Efficiency of water heater | | 90.0 | | (86) |
| Water heating fuel | | | 3688 | (86a) |
| Electricity for pumps and fans | | | 130 | (87) |
| Electricity for lighting (30% fixed LEL) | | | 821 | (87g) |

10a and 11a do not apply

| 12a. Carbon dioxide emissions | Energy (kWh/year) | Emission factor | Emissions (kg/year) | |
|---|---|---|---|---|
| Space heating, main - box (85) | 17403 | 0.194 | 3376 | (101) |
| Space heating, secondary - box (85a) | 1740 | 0.422 | 734 | (102) |
| Water heating - box (86a) | 3688 | 0.194 | 716 | (103) |
| Space and water heating | | | 4826 | (107) |
| Pumps and fans - box (87) | 130 | 0.422 | 55 | (108) |
| Electricity for lighting | 821 | 0.422 | 346 | (109) |
| Total kg/year | | | 5227 | (112) |
| | | | kg/m²/year | |
| **Dwelling Carbon Dioxide Emission Rate (DER)** | | | **50.26** | (113) |

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**Bing Part2 Existing EPS in Temperate Oceanic (TO)**

1. Overall dwelling dimensions

| | Area ($m^2$) | Av. storey height (m) | Volume ($m^3$) | |
|---|---|---|---|---|
| Ground floor | 52.00 | 2.40 | 124.80 | (1) |
| First floor | 52.00 | 2.60 | 135.20 | (2) |
| Total floor area | 104.00 | | | (5) |
| Dwelling volume ($m^3$) | | | 260.00 | (6) |

2. Ventilation rate

| | | $m^3$ per hour | ach | |
|---|---|---|---|---|
| Number of chimneys | 0 × 40 | 0 | | (7) |
| Number of flues | 0 × 20 | 0 | | (8) |
| Number of fans or passive vents | 2 × 10 | 20 | | (9) |
| Number of flueless gas fires | 0 × 40 | 0 | | (9a) |
| Infiltration due to chimneys, flues and fans | | | 0.08 | (10) |
| Pressure test | Yes | | | |
| Measured/design q50 | 10.0 | | | |
| Infiltration rate | | | 0.58 | (19) |
| Number of sides sheltered | 2 | | | (20) |
| Shelter factor | 0.85 | | | (21) |
| Adjusted infiltration rate | | | 0.49 | (22) |
| Natural ventilation | | | | |
| Effective air change rate | | | 0.62 | (25) |

3. Heat losses and heat loss parameter

| Element | Area ($m^2$) | U-value ($W/m^2K$) | A × U (W/K) | |
|---|---|---|---|---|
| Doors | 3.80 | 2.85 | 10.83 | (26) |
| Windows | 16.90 | (2.70) 2.44 | 41.18 | (27) |
| Ground floor | 52.00 | 0.67 | 34.84 | (28) |
| Walls | 120.80 | 0.47 | 56.78 | (29) |
| Roof | 52.00 | 0.40 | 20.80 | (30) |
| Total area of elements | 245.50 | | | (32) |
| Fabric heat loss | | | 164.43 | (33) |
| Thermal bridges (0.15 × total area) | | | 36.83 | (34) |
| Total fabric heat loss | | | 201.25 | (35) |
| Ventilation heat loss | | | 53.22 | (36) |
| Heat loss coefficient | | | 254.47 | (37) |
| Heat loss parameter (HLP) | | | 2.45 | (38) |

4. Water heating energy requirements

| | | kWh/year | |
|---|---|---|---|
| Energy content of heated water | | 2152 | (39) |
| Distribution loss | | 380 | (40) |
| Cylinder volume | 120 | | (43) |
| Cylinder loss factor (kWh/litre/day) | 0.0181 | | (44) |
| Volume factor | 1.000 | | (44a) |
| Temperature factor | 0.54 | | (44b) |
| Energy lost from cylinder in kWh/year (120 litres) | | 428 | (47) |
| Primary circuit loss | | 360 | (48) |
| Total | | 3319 | (49a) |
| Solar input | | 0 | (50) |
| Output from water heater | | 3319 | (51) |
| Heat gains from water heating | | 1472 | (52) |

5. Internal gains

| | Watts | |
|---|---|---|
| Lights, appliances, cooking and metabolic | 594 | (53) |
| Reduction in lighting gains | -22 | (53a) |
| Additional gains (Table 5a) | 10 | (53b) |
| Water heating | 168 | (54) |
| Total internal gains | 751 | (55) |

6. Solar gains

| Orientation | | Area | Flux | g | FF | Shading | | Gains (W) |
|---|---|---|---|---|---|---|---|---|
| East/West | 0.9 × | 16.90 | 50 | 0.76 | 0.70 | 0.77 | 312 | (58) |
| | | | | | | total: | 312 | (65) |

| | | |
|---|---|---|
| Total gains | 1062 | (66) |
| Gain/loss ratio | 4.17 | (67) |
| Utilisation factor | 0.987 | (68) |
| Useful gains | 1048 | (69) |

7. Mean internal temperature

| | °C | |
|---|---|---|
| Mean temperature of the living area | 18.81 | (70) |
| Temperature adjustment from Table 4e | 0.00 | (71) |
| Adjustment for gains | 0.02 | (72) |
| Adjusted living area temperature | 18.84 | (73) |
| Temperature difference between zones | 1.64 | (74) |
| Living area fraction | 0.186 | (75) |
| Rest-of-house area fraction | 0.814 | (76) |
| Mean internal temperature | 17.50 | (77) |

8. Degree-days

| | | |
|---|---|---|
| Temperature rise from gains | 4.12 | (78) |
| Base temperature | 13.38 | (79) |
| Degree-days | 1644.3 | (80) |

| 9a. Energy requirements | | | kWh/year | |
|---|---|---|---|---|
| Space heating requirement (useful) | | | 8897 | (81) |
| Fraction of heat from secondary system (assumed for the calculation) | | 0.10 | | (82) |
| Efficiency of main heating system | | 90.0 | | (83) |
| Efficiency of secondary heating system | | 100 | | (84) |
| Space heating fuel (main) | | | 8897 | (85) |
| Space heating fuel (secondary) | | | 890 | (85a) |
| Water heating requirement | 3319 | | | |
| Efficiency of water heater | | 90.0 | | (86) |
| Water heating fuel | | | 3688 | (86a) |
| Electricity for pumps and fans | | | 130 | (87) |
| Electricity for lighting (30% fixed LEL) | | | 821 | (87g) |

10a and 11a do not apply

| 12a. Carbon dioxide emissions | Energy (kWh/year) | Emission factor | Emissions (kg/year) | |
|---|---|---|---|---|
| Space heating, main - box (85) | 8897 | 0.194 | 1726 | (101) |
| Space heating, secondary - box (85a) | 890 | 0.422 | 375 | (102) |
| Water heating - box (86a) | 3688 | 0.194 | 716 | (103) |
| Space and water heating | | | 2817 | (107) |
| Pumps and fans - box (87) | 130 | 0.422 | 55 | (108) |
| Electricity for lighting | 821 | 0.422 | 346 | (109) |
| Total kg/year | | | 3218 | (112) |
| | | | kg/m²/year | |
| **Dwelling Carbon Dioxide Emission Rate (DER)** | | | **30.95** | (113) |

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**Approved Document L1A, 2006 Edition**

**Bing Part2 Existing EPS in Temperate Mediterranean (TM)**

1. Overall dwelling dimensions

| | Area ($m^2$) | Av. storey height (m) | Volume ($m^3$) | |
|---|---|---|---|---|
| Ground floor | 52.00 | 2.40 | 124.80 | (1) |
| First floor | 52.00 | 2.60 | 135.20 | (2) |
| Total floor area | 104.00 | | | (5) |
| Dwelling volume ($m^3$) | | | 260.00 | (6) |

2. Ventilation rate

| | | m³ per hour | ach | |
|---|---|---|---|---|
| Number of chimneys | 0 × 40 | 0 | | (7) |
| Number of flues | 0 × 20 | 0 | | (8) |
| Number of fans or passive vents | 2 × 10 | 20 | | (9) |
| Number of flueless gas fires | 0 × 40 | 0 | | (9a) |
| Infiltration due to chimneys, flues and fans | | | 0.08 | (10) |
| Pressure test | Yes | | | |
| Measured/design q50 | 10.0 | | | |
| Infiltration rate | | | 0.58 | (19) |
| Number of sides sheltered | 2 | | | (20) |
| Shelter factor | 0.85 | | | (21) |
| Adjusted infiltration rate | | | 0.49 | (22) |
| Natural ventilation | | | | |
| Effective air change rate | | | 0.62 | (25) |

3. Heat losses and heat loss parameter

| Element | Area ($m^2$) | U-value ($W/m^2K$) | A × U (W/K) | |
|---|---|---|---|---|
| Doors | 3.80 | 2.85 | 10.83 | (26) |
| Windows | 16.90 | (2.70) 2.44 | 41.18 | (27) |
| Ground floor | 52.00 | 0.67 | 34.84 | (28) |
| Walls | 120.80 | 0.47 | 56.78 | (29) |
| Roof | 52.00 | 0.40 | 20.80 | (30) |
| Total area of elements | 245.50 | | | (32) |
| Fabric heat loss | | | 164.43 | (33) |
| Thermal bridges (0.15 × total area) | | | 36.83 | (34) |
| Total fabric heat loss | | | 201.25 | (35) |
| Ventilation heat loss | | | 53.22 | (36) |
| Heat loss coefficient | | | 254.47 | (37) |
| Heat loss parameter (HLP) | | | 2.45 | (38) |

4. Water heating energy requirements

| | | kWh/year | |
|---|---|---|---|
| Energy content of heated water | | 2152 | (39) |
| Distribution loss | | 380 | (40) |
| Cylinder volume | 120 | | (43) |
| Cylinder loss factor (kWh/litre/day) | 0.0181 | | (44) |
| Volume factor | 1.000 | | (44a) |
| Temperature factor | 0.54 | | (44b) |
| Energy lost from cylinder in kWh/year (120 litres) | | 428 | (47) |
| Primary circuit loss | | 360 | (48) |
| Total | | 3319 | (49a) |
| Solar input | | 0 | (50) |
| Output from water heater | | 3319 | (51) |
| Heat gains from water heating | | 1472 | (52) |

5. Internal gains

| | Watts | |
|---|---|---|
| Lights, appliances, cooking and metabolic | 594 | (53) |
| Reduction in lighting gains | -22 | (53a) |
| Additional gains (Table 5a) | 10 | (53b) |
| Water heating | 168 | (54) |
| Total internal gains | 751 | (55) |

6. Solar gains

| Orientation | | Area | Flux | g | FF | Shading | | Gains (W) |
|---|---|---|---|---|---|---|---|---|
| East/West | 0.9 × | 16.90 | 68 | 0.76 | 0.70 | 0.77 | 424 | (58) |
| | | | | | | total: | 424 | (65) |

| | | |
|---|---|---|
| Total gains | 1174 | (66) |
| Gain/loss ratio | 4.62 | (67) |
| Utilisation factor | 0.980 | (68) |
| Useful gains | 1151 | (69) |

7. Mean internal temperature

| | °C | |
|---|---|---|
| Mean temperature of the living area | 18.81 | (70) |
| Temperature adjustment from Table 4e | 0.00 | (71) |
| Adjustment for gains | 0.10 | (72) |
| Adjusted living area temperature | 18.92 | (73) |
| Temperature difference between zones | 1.64 | (74) |
| Living area fraction | 0.186 | (75) |
| Rest-of-house area fraction | 0.814 | (76) |
| Mean internal temperature | 17.58 | (77) |

8. Degree-days

| | | |
|---|---|---|
| Temperature rise from gains | 4.52 | (78) |
| Base temperature | 13.06 | (79) |
| Degree-days | 1573.4 | (80) |

| 9a. Energy requirements | | | kWh/year | |
|---|---|---|---|---|
| Space heating requirement (useful) | | | 7270 | (81) |
| Fraction of heat from secondary system (assumed for the calculation) | | 0.10 | | (82) |
| Efficiency of main heating system | | 90.0 | | (83) |
| Efficiency of secondary heating system | | 100 | | (84) |
| Space heating fuel (main) | | | 7270 | (85) |
| Space heating fuel (secondary) | | | 727 | (85a) |
| Water heating requirement | 3319 | | | |
| Efficiency of water heater | | 90.0 | | (86) |
| Water heating fuel | | | 3688 | (86a) |
| Electricity for pumps and fans | | | 130 | (87) |
| Electricity for lighting (30% fixed LEL) | | | 821 | (87g) |

10a and 11a do not apply

| 12a. Carbon dioxide emissions | Energy (kWh/year) | Emission factor | Emissions (kg/year) | |
|---|---|---|---|---|
| Space heating, main - box (85) | 7270 | 0.194 | 1410 | (101) |
| Space heating, secondary - box (85a) | 727 | 0.422 | 307 | (102) |
| Water heating - box (86a) | 3688 | 0.194 | 716 | (103) |
| Space and water heating | | | 2433 | (107) |
| Pumps and fans - box (87) | 130 | 0.422 | 55 | (108) |
| Electricity for lighting | 821 | 0.422 | 346 | (109) |
| Total kg/year | | | 2834 | (112) |
| | | | kg/m²/year | |
| **Dwelling Carbon Dioxide Emission Rate (DER)** | | | **27.25** | (113) |

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**Bing Part2 Existing EPS in Cool Continental (CC)**

1. Overall dwelling dimensions

| | Area ($m^2$) | Av. storey height (m) | Volume ($m^3$) | |
|---|---|---|---|---|
| Ground floor | 52.00 | 2.40 | 124.80 | (1) |
| First floor | 52.00 | 2.60 | 135.20 | (2) |
| Total floor area | 104.00 | | | (5) |
| Dwelling volume ($m^3$) | | | 260.00 | (6) |

2. Ventilation rate

| | | m³ per hour | ach | |
|---|---|---|---|---|
| Number of chimneys | 0 × 40 | 0 | | (7) |
| Number of flues | 0 × 20 | 0 | | (8) |
| Number of fans or passive vents | 2 × 10 | 20 | | (9) |
| Number of flueless gas fires | 0 × 40 | 0 | | (9a) |
| Infiltration due to chimneys, flues and fans | | | 0.08 | (10) |
| Pressure test | Yes | | | |
| Measured/design q50 | 10.0 | | | |
| Infiltration rate | | | 0.58 | (19) |
| Number of sides sheltered | 2 | | | (20) |
| Shelter factor | 0.85 | | | (21) |
| Adjusted infiltration rate | | | 0.49 | (22) |
| Natural ventilation | | | | |
| Effective air change rate | | | 0.62 | (25) |

3. Heat losses and heat loss parameter

| Element | Area ($m^2$) | U-value ($W/m^2K$) | A × U (W/K) | |
|---|---|---|---|---|
| Doors | 3.80 | 2.85 | 10.83 | (26) |
| Windows | 16.90 | (2.70) 2.44 | 41.18 | (27) |
| Ground floor | 52.00 | 0.67 | 34.84 | (28) |
| Walls | 120.80 | 0.47 | 56.78 | (29) |
| Roof | 52.00 | 0.40 | 20.80 | (30) |
| Total area of elements | 245.50 | | | (32) |
| Fabric heat loss | | | 164.43 | (33) |
| Thermal bridges (0.15 × total area) | | | 36.83 | (34) |
| Total fabric heat loss | | | 201.25 | (35) |
| Ventilation heat loss | | | 53.22 | (36) |
| Heat loss coefficient | | | 254.47 | (37) |
| Heat loss parameter (HLP) | | | 2.45 | (38) |

4. Water heating energy requirements

| | | kWh/year | |
|---|---|---|---|
| Energy content of heated water | | 2152 | (39) |
| Distribution loss | | 380 | (40) |
| Cylinder volume | 120 | | (43) |
| Cylinder loss factor (kWh/litre/day) | 0.0181 | | (44) |
| Volume factor | 1.000 | | (44a) |
| Temperature factor | 0.54 | | (44b) |
| Energy lost from cylinder in kWh/year (120 litres) | | 428 | (47) |
| Primary circuit loss | | 360 | (48) |
| Total | | 3319 | (49a) |
| Solar input | | 0 | (50) |
| Output from water heater | | 3319 | (51) |
| Heat gains from water heating | | 1472 | (52) |

5. Internal gains

| | Watts | |
|---|---|---|
| Lights, appliances, cooking and metabolic | 594 | (53) |
| Reduction in lighting gains | -22 | (53a) |
| Additional gains (Table 5a) | 10 | (53b) |
| Water heating | 168 | (54) |
| Total internal gains | 751 | (55) |

6. Solar gains

| Orientation | | Area | Flux | g | FF | Shading | | Gains (W) |
|---|---|---|---|---|---|---|---|---|
| East/West | 0.9 × | 16.90 | 46 | 0.76 | 0.70 | 0.77 | 287 | (58) |
| | | | | | | total: | 287 | (65) |

| | | |
|---|---|---|
| Total gains | 1037 | (66) |
| Gain/loss ratio | 4.08 | (67) |
| Utilisation factor | 0.988 | (68) |
| Useful gains | 1025 | (69) |

| 7. Mean internal temperature | °C | |
|---|---|---|
| Mean temperature of the living area | 18.81 | (70) |
| Temperature adjustment from Table 4e | 0.00 | (71) |
| Adjustment for gains | 0.01 | (72) |
| Adjusted living area temperature | 18.82 | (73) |
| Temperature difference between zones | 1.64 | (74) |
| Living area fraction | 0.186 | (75) |
| Rest-of-house area fraction | 0.814 | (76) |
| Mean internal temperature | 17.48 | (77) |

8. Degree-days

| | | |
|---|---|---|
| Temperature rise from gains | 4.03 | (78) |
| Base temperature | 13.46 | (79) |
| Degree-days | 1660.4 | (80) |

| | | | | |
|---|---|---|---|---|
| 9a. Energy requirements | | | kWh/year | |
| Space heating requirement (useful) | | | 18566 | (81) |
| Fraction of heat from secondary system (assumed for the calculation) | | 0.10 | | (82) |
| Efficiency of main heating system | | 90.0 | | (83) |
| Efficiency of secondary heating system | | 100 | | (84) |
| Space heating fuel (main) | | | 18566 | (85) |
| Space heating fuel (secondary) | | | 1857 | (85a) |
| Water heating requirement | 3319 | | | |
| Efficiency of water heater | | 90.0 | | (86) |
| Water heating fuel | | | 3688 | (86a) |
| Electricity for pumps and fans | | | 130 | (87) |
| Electricity for lighting (30% fixed LEL) | | | 821 | (87g) |

10a and 11a do not apply

| 12a. Carbon dioxide emissions | Energy (kWh/year) | Emission factor | Emissions (kg/year) | |
|---|---|---|---|---|
| Space heating, main - box (85) | 18566 | 0.194 | 3602 | (101) |
| Space heating, secondary - box (85a) | 1857 | 0.422 | 783 | (102) |
| Water heating - box (86a) | 3688 | 0.194 | 716 | (103) |
| Space and water heating | | | 5101 | (107) |
| Pumps and fans - box (87) | 130 | 0.422 | 55 | (108) |
| Electricity for lighting | 821 | 0.422 | 346 | (109) |
| Total kg/year | | | 5502 | (112) |
| | | | kg/m²/year | |
| **Dwelling Carbon Dioxide Emission Rate (DER)** | | | **52.90** | (113) |

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**Bing Part 3 - Newbuild Flat Roof in Temperate Oceanic (TO)**

| 1. Overall dwelling dimensions | Area ($m^2$) | Av. storey height (m) | Volume ($m^3$) | |
|---|---|---|---|---|
| Ground floor | 52.00 | 2.40 | 124.80 | (1) |
| First floor | 52.00 | 2.60 | 135.20 | (2) |
| Total floor area | 104.00 | | | (5) |
| Dwelling volume ($m^3$) | | | 260.00 | (6) |

| 2. Ventilation rate | | $m^3$ per hour | ach | |
|---|---|---|---|---|
| Number of chimneys | 0 × 40 | 0 | | (7) |
| Number of flues | 0 × 20 | 0 | | (8) |
| Number of fans or passive vents | 2 × 10 | 20 | | (9) |
| Number of flueless gas fires | 0 × 40 | 0 | | (9a) |
| Infiltration due to chimneys, flues and fans | | | 0.08 | (10) |
| Pressure test | Yes | | | |
| Measured/design q50 | 10.0 | | | |
| Infiltration rate | | | 0.58 | (19) |
| Number of sides sheltered | 2 | | | (20) |
| Shelter factor | 0.85 | | | (21) |
| Adjusted infiltration rate | | | 0.49 | (22) |
| Natural ventilation | | | | |
| Effective air change rate | | | 0.62 | (25) |

3. Heat losses and heat loss parameter

| Element | Area ($m^2$) | U-value ($W/m^2K$) | A × U (W/K) | |
|---|---|---|---|---|
| Doors | 3.80 | 2.85 | 10.83 | (26) |
| Windows | 16.90 | (2.10) 1.94 | 32.74 | (27) |
| Ground floor | 52.00 | 0.18 | 9.36 | (28) |
| Walls | 120.80 | 0.15 | 18.12 | (29) |
| Roof | 52.00 | 0.15 | 7.80 | (30) |
| Total area of elements | 245.50 | | | (32) |
| Fabric heat loss | | | 78.85 | (33) |
| Thermal bridges (0.08 × total area) | | | 19.64 | (34) |
| Total fabric heat loss | | | 98.49 | (35) |
| Ventilation heat loss | | | 53.22 | (36) |
| Heat loss coefficient | | | 151.71 | (37) |
| Heat loss parameter (HLP) | | | 1.46 | (38) |

4. Water heating energy requirements

| | | kWh/year | |
|---|---|---|---|
| Energy content of heated water | | 2152 | (39) |
| Distribution loss | | 380 | (40) |
| Cylinder volume | 120 | | (43) |
| Cylinder loss factor (kWh/litre/day) | 0.0181 | | (44) |
| Volume factor | 1.000 | | (44a) |
| Temperature factor | 0.54 | | (44b) |
| Energy lost from cylinder in kWh/year (120 litres) | | 428 | (47) |
| Primary circuit loss | | 360 | (48) |
| Total | | 3319 | (49a) |
| Solar input | | 0 | (50) |
| Output from water heater | | 3319 | (51) |
| Heat gains from water heating | | 1472 | (52) |

5. Internal gains

| | Watts | |
|---|---|---|
| Lights, appliances, cooking and metabolic | 594 | (53) |
| Reduction in lighting gains | -22 | (53a) |
| Additional gains (Table 5a) | 10 | (53b) |
| Water heating | 168 | (54) |
| Total internal gains | 751 | (55) |

6. Solar gains

| Orientation | | Area | Flux | g | FF | Shading | | Gains (W) |
|---|---|---|---|---|---|---|---|---|
| East/West | 0.9 × | 16.90 | 50 | 0.72 | 0.70 | 0.77 | 295 | (58) |
| | | | | | | total: | 295 | (65) |

| | | |
|---|---|---|
| Total gains | 1046 | (66) |
| Gain/loss ratio | 6.89 | (67) |
| Utilisation factor | 0.927 | (68) |
| Useful gains | 969 | (69) |

7. Mean internal temperature

| | °C | |
|---|---|---|
| Mean temperature of the living area | 18.88 | (70) |
| Temperature adjustment from Table 4e | 0.00 | (71) |
| Adjustment for gains | 0.48 | (72) |
| Adjusted living area temperature | 19.36 | (73) |
| Temperature difference between zones | 1.48 | (74) |
| Living area fraction | 0.186 | (75) |
| Rest-of-house area fraction | 0.814 | (76) |
| Mean internal temperature | 18.15 | (77) |

8. Degree-days

| | | |
|---|---|---|
| Temperature rise from gains | 6.39 | (78) |
| Base temperature | 11.76 | (79) |
| Degree-days | 1295.1 | (80) |

| 9a. Energy requirements | | | kWh/year | |
|---|---|---|---|---|
| Space heating requirement (useful) | | | 4059 | (81) |
| Fraction of heat from secondary system (assumed for the calculation) | | 0.10 | | (82) |
| Efficiency of main heating system | | 90.0 | | (83) |
| Efficiency of secondary heating system | | 100 | | (84) |
| Space heating fuel (main) | | | 4059 | (85) |
| Space heating fuel (secondary) | | | 406 | (85a) |
| Water heating requirement | 3319 | | | |
| Efficiency of water heater | | 90.0 | | (86) |
| Water heating fuel | | | 3688 | (86a) |
| Electricity for pumps and fans | | | 130 | (87) |
| Electricity for lighting (30% fixed LEL) | | | 821 | (87g) |

10a and 11a do not apply

| 12a. Carbon dioxide emissions | Energy (kWh/year) | Emission factor | Emissions (kg/year) | |
|---|---|---|---|---|
| Space heating, main - box (85) | 4059 | 0.194 | 788 | (101) |
| Space heating, secondary - box (85a) | 406 | 0.422 | 171 | (102) |
| Water heating - box (86a) | 3688 | 0.194 | 716 | (103) |
| Space and water heating | | | 1674 | (107) |
| Pumps and fans - box (87) | 130 | 0.422 | 55 | (108) |
| Electricity for lighting | 821 | 0.422 | 346 | (109) |
| Total kg/year | | | 2076 | (112) |
| | | | kg/m²/year | |
| **Dwelling Carbon Dioxide Emission Rate (DER)** | | | **19.96** | (113) |

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**Bing Part 3 - Newbuild Flat Roof in Temperate Mediterranean (TM)**

1. Overall dwelling dimensions

| | Area ($m^2$) | Av. storey height (m) | Volume ($m^3$) | |
|---|---|---|---|---|
| Ground floor | 52.00 | 2.40 | 124.80 | (1) |
| First floor | 52.00 | 2.60 | 135.20 | (2) |
| Total floor area | 104.00 | | | (5) |
| Dwelling volume ($m^3$) | | | 260.00 | (6) |

2. Ventilation rate

| | | $m^3$ per hour | ach | |
|---|---|---|---|---|
| Number of chimneys | 0 × 40 | 0 | | (7) |
| Number of flues | 0 × 20 | 0 | | (8) |
| Number of fans or passive vents | 2 × 10 | 20 | | (9) |
| Number of flueless gas fires | 0 × 40 | 0 | | (9a) |
| Infiltration due to chimneys, flues and fans | | | 0.08 | (10) |
| Pressure test | Yes | | | |
| Measured/design q50 | 10.0 | | | |
| Infiltration rate | | | 0.58 | (19) |
| Number of sides sheltered | 2 | | | (20) |
| Shelter factor | 0.85 | | | (21) |
| Adjusted infiltration rate | | | 0.49 | (22) |
| Natural ventilation | | | | |
| Effective air change rate | | | 0.62 | (25) |

3. Heat losses and heat loss parameter

| Element | Area ($m^2$) | U-value ($W/m^2K$) | A × U (W/K) | |
|---|---|---|---|---|
| Doors | 3.80 | 2.85 | 10.83 | (26) |
| Windows | 16.90 | (2.10) 1.94 | 32.74 | (27) |
| Ground floor | 52.00 | 0.18 | 9.36 | (28) |
| Walls | 120.80 | 0.15 | 18.12 | (29) |
| Roof | 52.00 | 0.15 | 7.80 | (30) |
| Total area of elements | 245.50 | | | (32) |
| Fabric heat loss | | | 78.85 | (33) |
| Thermal bridges (0.08 × total area) | | | 19.64 | (34) |
| Total fabric heat loss | | | 98.49 | (35) |
| Ventilation heat loss | | | 53.22 | (36) |
| Heat loss coefficient | | | 151.71 | (37) |
| Heat loss parameter (HLP) | | | 1.46 | (38) |

4. Water heating energy requirements

| | | kWh/year | |
|---|---|---|---|
| Energy content of heated water | | 2152 | (39) |
| Distribution loss | | 380 | (40) |
| Cylinder volume | 120 | | (43) |
| Cylinder loss factor (kWh/litre/day) | 0.0181 | | (44) |
| Volume factor | 1.000 | | (44a) |
| Temperature factor | 0.54 | | (44b) |
| Energy lost from cylinder in kWh/year (120 litres) | | 428 | (47) |
| Primary circuit loss | | 360 | (48) |
| Total | | 3319 | (49a) |
| Solar input | | 0 | (50) |
| Output from water heater | | 3319 | (51) |
| Heat gains from water heating | | 1472 | (52) |

5. Internal gains

| | Watts | |
|---|---|---|
| Lights, appliances, cooking and metabolic | 594 | (53) |
| Reduction in lighting gains | -22 | (53a) |
| Additional gains (Table 5a) | 10 | (53b) |
| Water heating | 168 | (54) |
| Total internal gains | 751 | (55) |

6. Solar gains

| Orientation | | Area | Flux | g | FF | Shading | | Gains (W) |
|---|---|---|---|---|---|---|---|---|
| East/West | 0.9 × | 16.90 | 68 | 0.72 | 0.70 | 0.77 | 401 | (58) |
| | | | | | | total: | 401 | (65) |

| | | |
|---|---|---|
| Total gains | 1152 | (66) |
| Gain/loss ratio | 7.59 | (67) |
| Utilisation factor | 0.907 | (68) |
| Useful gains | 1044 | (69) |

7. Mean internal temperature

| | °C | |
|---|---|---|
| Mean temperature of the living area | 18.88 | (70) |
| Temperature adjustment from Table 4e | 0.00 | (71) |
| Adjustment for gains | 0.58 | (72) |
| Adjusted living area temperature | 19.46 | (73) |
| Temperature difference between zones | 1.48 | (74) |
| Living area fraction | 0.186 | (75) |
| Rest-of-house area fraction | 0.814 | (76) |
| Mean internal temperature | 18.25 | (77) |

8. Degree-days

| | | |
|---|---|---|
| Temperature rise from gains | 6.88 | (78) |
| Base temperature | 11.36 | (79) |
| Degree-days | 1213.0 | (80) |

| 9a. Energy requirements | | | kWh/year | |
|---|---|---|---|---|
| Space heating requirement (useful) | | | 3317 | (81) |
| Fraction of heat from secondary system (assumed for the calculation) | | 0.10 | | (82) |
| Efficiency of main heating system | | 90.0 | | (83) |
| Efficiency of secondary heating system | | 100 | | (84) |
| Space heating fuel (main) | | | 3317 | (85) |
| Space heating fuel (secondary) | | | 332 | (85a) |
| Water heating requirement | 3319 | | | |
| Efficiency of water heater | | 90.0 | | (86) |
| Water heating fuel | | | 3688 | (86a) |
| Electricity for pumps and fans | | | 130 | (87) |
| Electricity for lighting (30% fixed LEL) | | | 821 | (87g) |

10a and 11a do not apply

| 12a. Carbon dioxide emissions | Energy (kWh/year) | Emission factor | Emissions (kg/year) | |
|---|---|---|---|---|
| Space heating, main - box (85) | 3317 | 0.194 | 643 | (101) |
| Space heating, secondary - box (85a) | 332 | 0.422 | 140 | (102) |
| Water heating - box (86a) | 3688 | 0.194 | 716 | (103) |
| Space and water heating | | | 1499 | (107) |
| Pumps and fans - box (87) | 130 | 0.422 | 55 | (108) |
| Electricity for lighting | 821 | 0.422 | 346 | (109) |
| Total kg/year | | | 1900 | (112) |
| | | | kg/m²/year | |
| **Dwelling Carbon Dioxide Emission Rate (DER)** | | | **18.27** | (113) |

**SAP 2005 WORKSHEET FOR NEW DWELLING AS DESIGNED** (Version 9.82, June 2008)
**CALCULATION OF DWELLING EMISSIONS FOR REGULATIONS COMPLANCE**
**Approved Document L1A, 2006 Edition**

**Bing Part 3 - Newbuild Flat Roof in Cool Continental (CC)**

| 1. Overall dwelling dimensions | Area (m²) | Av. storey height (m) | Volume (m³) | |
|---|---|---|---|---|
| Ground floor | 52.00 | 2.40 | 124.80 | (1) |
| First floor | 52.00 | 2.60 | 135.20 | (2) |
| Total floor area | 104.00 | | | (5) |
| Dwelling volume (m³) | | | 260.00 | (6) |

| 2. Ventilation rate | | m³ per hour | ach | |
|---|---|---|---|---|
| Number of chimneys | 0 × 40 | 0 | | (7) |
| Number of flues | 0 × 20 | 0 | | (8) |
| Number of fans or passive vents | 2 × 10 | 20 | | (9) |
| Number of flueless gas fires | 0 × 40 | 0 | | (9a) |
| Infiltration due to chimneys, flues and fans | | | 0.08 | (10) |
| Pressure test | Yes | | | |
| Measured/design q50 | 10.0 | | | |
| Infiltration rate | | | 0.58 | (19) |
| Number of sides sheltered | 2 | | | (20) |
| Shelter factor | 0.85 | | | (21) |
| Adjusted infiltration rate | | | 0.49 | (22) |
| Natural ventilation | | | | |
| Effective air change rate | | | 0.62 | (25) |

3. Heat losses and heat loss parameter

| Element | Area (m²) | U-value (W/m²K) | A × U (W/K) | |
|---|---|---|---|---|
| Doors | 3.80 | 2.85 | 10.83 | (26) |
| Windows | 16.90 | (2.10) 1.94 | 32.74 | (27) |
| Ground floor | 52.00 | 0.18 | 9.36 | (28) |
| Walls | 120.80 | 0.15 | 18.12 | (29) |
| Roof | 52.00 | 0.15 | 7.80 | (30) |
| Total area of elements | 245.50 | | | (32) |
| Fabric heat loss | | | 78.85 | (33) |
| Thermal bridges (0.08 × total area) | | | 19.64 | (34) |
| Total fabric heat loss | | | 98.49 | (35) |
| Ventilation heat loss | | | 53.22 | (36) |
| Heat loss coefficient | | | 151.71 | (37) |
| Heat loss parameter (HLP) | | | 1.46 | (38) |

4. Water heating energy requirements

| | | kWh/year | |
|---|---|---|---|
| Energy content of heated water | | 2152 | (39) |
| Distribution loss | | 380 | (40) |
| Cylinder volume | 120 | | (43) |
| Cylinder loss factor (kWh/litre/day) | 0.0181 | | (44) |
| Volume factor | 1.000 | | (44a) |
| Temperature factor | 0.54 | | (44b) |
| Energy lost from cylinder in kWh/year (120 litres) | | 428 | (47) |
| Primary circuit loss | | 360 | (48) |
| Total | | 3319 | (49a) |
| Solar input | | 0 | (50) |
| Output from water heater | | 3319 | (51) |
| Heat gains from water heating | | 1472 | (52) |

5. Internal gains

| | Watts | |
|---|---|---|
| Lights, appliances, cooking and metabolic | 594 | (53) |
| Reduction in lighting gains | -22 | (53a) |
| Additional gains (Table 5a) | 10 | (53b) |
| Water heating | 168 | (54) |
| Total internal gains | 751 | (55) |

6. Solar gains

| Orientation | | Area | Flux | g | FF | Shading | | Gains (W) |
|---|---|---|---|---|---|---|---|---|
| East/West | 0.9 × | 16.90 | 46 | 0.72 | 0.70 | 0.77 | 272 | (58) |
| | | | | | | total: | 272 | (65) |

| | | |
|---|---|---|
| Total gains | 1022 | (66) |
| Gain/loss ratio | 6.74 | (67) |
| Utilisation factor | 0.931 | (68) |
| Useful gains | 952 | (69) |

7. Mean internal temperature

| | °C | |
|---|---|---|
| Mean temperature of the living area | 18.88 | (70) |
| Temperature adjustment from Table 4e | 0.00 | (71) |
| Adjustment for gains | 0.45 | (72) |
| Adjusted living area temperature | 19.33 | (73) |
| Temperature difference between zones | 1.48 | (74) |
| Living area fraction | 0.186 | (75) |
| Rest-of-house area fraction | 0.814 | (76) |
| Mean internal temperature | 18.13 | (77) |

8. Degree-days

| | | |
|---|---|---|
| Temperature rise from gains | 6.27 | (78) |
| Base temperature | 11.85 | (79) |
| Degree-days | 1314.5 | (80) |

| 9a. Energy requirements | | | kWh/year | |
|---|---|---|---|---|
| Space heating requirement (useful) | | | 9691 | (81) |
| Fraction of heat from secondary system (assumed for the calculation) | | 0.10 | | (82) |
| Efficiency of main heating system | | 90.0 | | (83) |
| Efficiency of secondary heating system | | 100 | | (84) |
| Space heating fuel (main) | | | 9691 | (85) |
| Space heating fuel (secondary) | | | 969 | (85a) |
| Water heating requirement | 3319 | | | |
| Efficiency of water heater | | 90.0 | | (86) |
| Water heating fuel | | | 3688 | (86a) |
| Electricity for pumps and fans | | | 130 | (87) |
| Electricity for lighting (30% fixed LEL) | | | 821 | (87g) |

10a and 11a do not apply

| 12a. Carbon dioxide emissions | Energy (kWh/year) | Emission factor | Emissions (kg/year) | |
|---|---|---|---|---|
| Space heating, main - box (85) | 9691 | 0.194 | 1880 | (101) |
| Space heating, secondary - box (85a) | 969 | 0.422 | 409 | (102) |
| Water heating - box (86a) | 3688 | 0.194 | 716 | (103) |
| Space and water heating | | | 3005 | (107) |
| Pumps and fans - box (87) | 130 | 0.422 | 55 | (108) |
| Electricity for lighting | 821 | 0.422 | 346 | (109) |
| Total kg/year | | | 3406 | (112) |
| | | | kg/m²/year | |
| **Dwelling Carbon Dioxide Emission Rate (DER)** | | | **32.75** | (113) |

## Appendix 5

### Life cycle stages impacts of PU insulation

The graphs below present the environmental impacts associated with the life cycle divided into the stages of manufacture, transport to site and disposal.

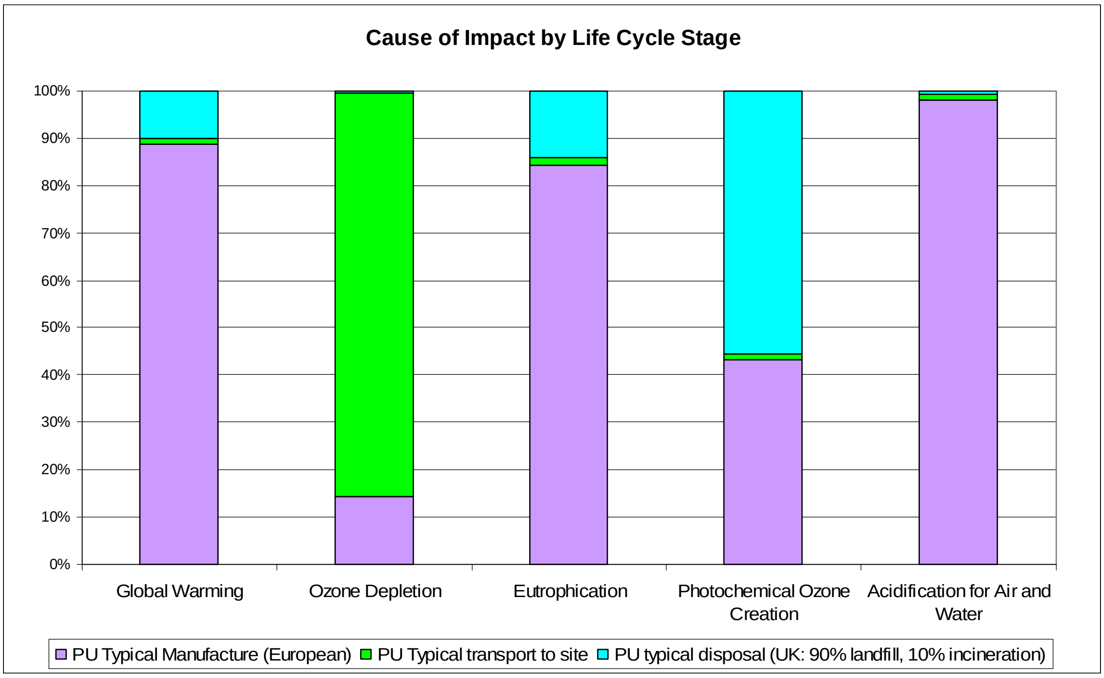


**Figure (A) Characterised impact of 1 tonne of PU insulation by life cycle stage.**

Figure A shows that the manufacture of the PU insulation dominates the impact categories Global Warming, Eutrophication and Acidification for Air and Water, and is also important in the Photochemical Ozone Creation category. Transport dominates the Ozone Depletion impact category.

Figure B below presents this data normalised to the annual impacts of a Western European citizen to show the relative sizes of these impact categories for each life cycle stage.

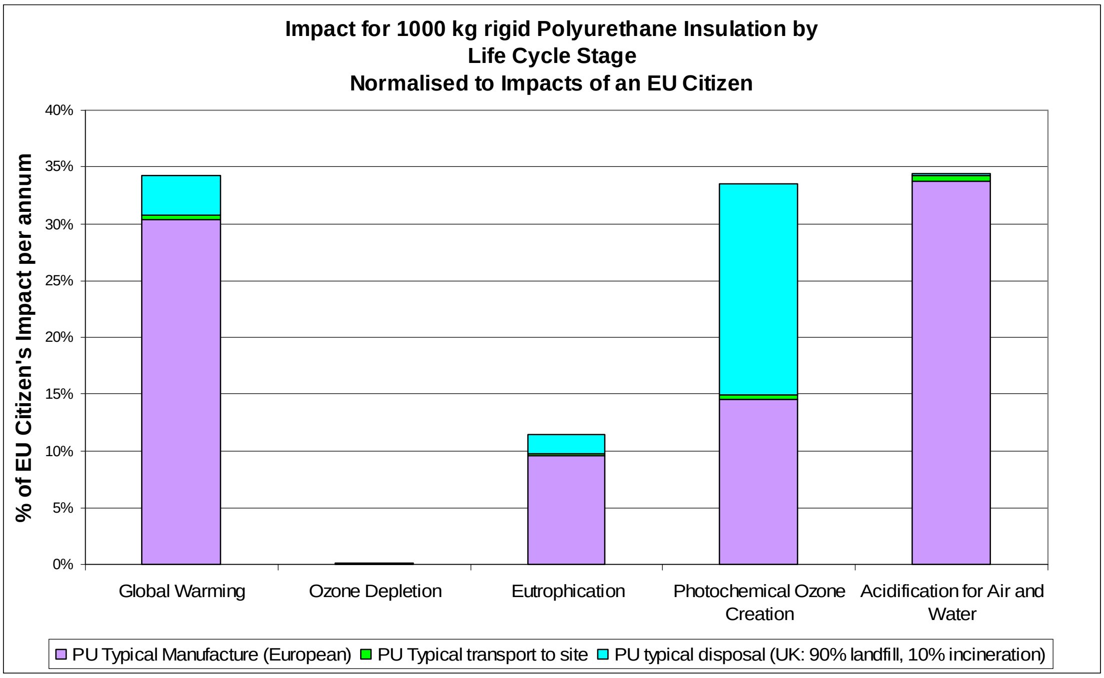


**Figure (B) Normalised impact of 1 tonne of PU insulation by life cycle stage.**

Figure B shows that Global Warming, Acidification for Air and Water and Photochemical Ozone Creation are the largest relative impacts, followed by Eutrophication. The impacts in Ozone Depletion are shown to be very small relative to the background level of impact in this category.